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Handbook for Quantitative Analysis of MANPRINT Considerations in Army Systems

Manned Systems Group
Systems Research Laboratory

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U. S. Army Research Institute for the Behavioral and Social Sciences

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This handbook briefly explains the necessity of including measures of soldier performance in forecasts of battlefield system performance. Then it presents a method for calculating estimates of manned system performance in the dimensions of effectiveness ("How well does it work when it works?") and availability ("How often does it work?"). The two equations are based on existing approaches for evaluating effectiveness and availability, but are modified to include estimates (based on actual measurements) of the probability of soldier performance satisfying both time and accuracy standards. Data sources (including operational testing) are discussed, and the user is led, step-by-step, through the calculations. A complete example of both calculations, using hypothetical but realistic data, is presented for the MANPACK Army User Equipment (AUE) of the GPS NAVSTAR system. After both effectiveness and availability calculations are made, use of the equations is demonstrated in an analysis mode for identifying which of the six domains of MANPRINT (manpower, personnel, training, human factors, system safety, and health hazards) may present performance problems.

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FOREWORD

This handbook is intended for Army personnel responsible for conducting evaluations of Manpower and Personnel Integration (MANPRINT) issues involved with the test and evaluation of Army systems. It contains an overview of the methodology and step-by-step instructions for accomplishing the recommended calculations, analyses, and evaluations.

A central premise of the MANPRINT Program is that "soldier performance affects system performance." This handbook provides the test and evaluation community with a way to translate that premise into specific, quantitative, analytic techniques for accounting for soldier performance in estimating the battlefield effectiveness and availability of manned systems.

The research effort leading to the MANPRINT Test and Evaluation Methodology described in this handbook was monitored by the Manned Systems Group of the Systems Research Laboratory of the U.S. Army Research Institute. Funding for this effort was provided by the U.S. Army Operational Test and Evaluation Agency (OTEA) pursuant to a Memorandum of Agreement signed 19 October 1984. This methodology was briefed to the Commander of OTEA on 21 April 1986 and to the Deputy Undersecretary of the Army (Operations Research) on 30 October 1986.

The MANPRINT Test and Evaluation Methodology may be used in all types of field tests--from early user test and experimentation through technical testing and user testing--wherever there is the desire to predict the battlefield effectiveness and availability of an Army system.

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Technical Director

HANDBOOK FOR QUANTITATIVE ANALYSIS OF MANPRINT CONSIDERATIONS IN ARMY SYSTEMS

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I. INTRODUCTION

What is MANPRINT?

MANPRINT (manpower and personnel integration) refers to the whole process of optimizing the relationship between *hardware/software and human performance*, which includes early and continuous attention to the following domains: manpower, personnel, training, human factors engineering, system safety, and health hazard assessment. There are two critical aspects of MANPRINT. The first links the design of the system to the expected field performance of it in the hands of the likely military operators and maintainers. That means that measures of effectiveness for system performance (such as calculations of system effectiveness and availability) now need to include quantitative soldier performance terms (which, in turn, have been shown to be heavily dependent on soldier aptitude and training). The second critical aspect of MANPRINT is its timing: the six domains must be considered early in the acquisition process, not after the prototype hardware and software have been made operational. In so doing, both the combat and the materiel developer will be able to influence the design of the system, and major problems in the interface of the six domains should be better identified and corrected early in the process.

Why is MANPRINT important?

MANPRINT is important to the Army's effort to achieve maximum battlefield effectiveness and a high state of readiness from technologically complex new weapon (and support) systems and from soldiers whose characteristics (e.g., aptitude) may not match those demanded by the system. Some key problems that MANPRINT seeks to avoid include:

(a) Failure to consider the size of the available manpower pool at the time when a system is to be fielded. This may result in a shortage of qualified personnel to fill available spaces, increased training and recruitment costs, and delayed deployment of the system.

(b) An increase in complexity of a new system over its predecessor may impose substantial new demands on the maintainers. This may result in a lack of a sufficient number of personnel with high enough aptitudes to perform required maintenance. At this stage, increased training time or costly equipment redesign may be the only means to offset the burden through reducing maintenance requirements.

(c) System effectiveness models and early developmental testing may predict a higher level of effectiveness than actually achieved by the average soldier who is expected to operate the system. This is often due to the failure to consider the average soldiers' capabilities and limitations in operating the equipment.

(d) A classic engineering problem: the controls on a new vehicle are the reverse of those on the old vehicle. No one realized that the same soldier may be required to drive both upon occasion. This may result in a design problem having a real impact on system safety.

What is the methodology for quantitative evaluation of soldier in system performance?

The methodology is derived from quantitative system analysis and modeling, human performance measurement and evaluation, and statistical techniques. It has two basic objectives. The first objective is to calculate the effect of soldier performance on system performance. The second objective is to determine the relationship between soldier characteristics (e.g., aptitude) and soldier performance. Two questions will be addressed in responding to the first objective. They are:

(a) How well does the system operate when operated by Army soldiers?

(b) How often does the system work when maintained by Army soldiers?

The first question involves the effectiveness of the system in

accomplishing required mission objectives. MANPRINT system effectiveness is the measure of effectiveness (MOE) for quantifying the role of soldier operations in effectiveness. The second question involves the availability of the system to demands for missions. MANPRINT availability is the MOE for quantifying the role of soldier maintenance in availability. Two questions will also be addressed in responding to the second objective. They are:

(a) Which soldier characteristics are related to soldier performance of critical operations and maintenance tasks?

(b) What improvements can be made in the system to alleviate problems associated with deficient soldier performance?

The first question involves the identification of soldier characteristics (e.g., aptitude, training, and physical attributes) which are required for critical operations and maintenance tasks? This is determined through correlation analysis of soldier characteristics data (e.g., ASVAB scores) with soldier performance data (e.g., time and accuracy in operations or maintenance tasks). The second question involves the determination of system improvements which could reduce the demand for scarce soldiers with the required characteristics.

<u>Data Requirements</u>

The measurement of soldier performance to support the evaluation and analysis of system MANPRINT issues should be in terms of both time and accuracy of soldiers performing critical operations and maintenance tasks. This quantitative soldier performance data should also be supplemented with qualitative data for use in MANPRINT analyses in which the diagnoses of the causes of soldier performance deficiencies are important. The quantitative

- MANPRINT Effectiveness (^{E}MANPRINT):
  - Operator Performance Probability on critical soldier tasks (specified through prior analysis)
  - System Performance Probability on critical system functions specified through prior analysis)
  - Human factors data on system operations (e.g., critical incidents, observations, surveys, interviews, and questionnaires)
- MANPRINT Availability (^{A}MANPRINT):
  - Mean Corrective Maintenance Time
    - Mean Preparation Time
    - Mean Fault Location Time
    - Mean Item Obtainment Time
    - Mean Fault Correction Time
    - Mean Adjustment/Calibration Time
    - Mean Checkout Time
    - Mean Cleanup Time
  - Probability of Correct Maintenance
  - Mean Preventive Maintenance Time
  - System/Equipment Reliability Data
  - Human factors data on maintenance activities (e.g., critical incidents, observations, surveys, interviews, and questionnaires)
- Personnel Characteristics of Test Participants:
  - Aptitude, e.g., ASVAB scores
  - Training, e.g., SQT scores
  - Physical Characteristics (e.g., PULHES)

Figure 1-1. MANPRINT measurement requirements

data can be collected by a variety of techniques, including: observation and scoring of soldier performance, instrumented data recording (e.g., 1553 data bus recording), and videotape recordings. The qualitative data can also be obtained through a variety of techniques, including: observation and recording of soldier performance, surveys, questionnaires, and interviews with soldiers and subject matter experts.

The reduced data requirements for supporting MANPRINT evaluations and analyses using this quantitative methodology should consist of summary soldier performance data which correspond to operator performance on critical tasks or maintainer performance on critical equipment for the system. The primary reduced data requirements for applying the quantitative MANPRINT methodology program are listed in Figure 1-1.

Test Participants

There are two factors to be considered with respect to the soldiers who participate as system operators and maintainers during testing: the number of participants and the comparison of the participants to the general populations of soldiers who will operate and maintain the system. While the tester cannot control the selection and assignment of participants, to the extent possible he should influence selection according to the factors discussed here.

For the purpose of MANPRINT evaluation and analysis, more participants are better. The methodology described here was developed, however, to work with as few as eight to ten participants performing the same tasks (e.g., system operation or maintenance). With fewer participants than this, evaluation in terms of effectiveness and availability can still be conducted; but many of the analyses described to diagnose specific MANPRINT problems are not valid. More than ten participants are desirable because as the number increases, the generalizability of test results to other soldier populations increases, as does confidence in the validity of test results.

It is also important for the test participants to span the range of the general operator/maintainer populations with respect to particular characteristics of interest (i.e., aptitude, training, MOS, etc.). That is, for example, for aptitude, the participants should include soldiers with aptitude area scores near the selection cutoff for the specified MOS as well as those with mid-range scores and high scores. If a large number of test participants is used, e.g., 80-100, this need can be accomplished by selecting participants that are representative of the general operator/maintainer populations. With smaller numbers of participants more care is needed in selection to ensure that the ranges of soldier characteristics are suitable. Although as mentioned above analyses can be performed with as few as eight to ten participants, this is true only if the participants are carefully selected as described.

Introduction to the MANPRINT Examples: the NAVSTAR Global Positioning System

A heavy use of examples is made in this handbook as a means to ease user understanding of the methodology. These examples employ a combination of actual and hypothetical soldier performance data based on test results from the Army's MANPACK Army User Equipment (AUE) of the NAVSTAR Global Positioning System (GPS). These examples are intended to be purely informative. They are certainly not intended to constitute an evaluation of the NAVSTAR system, since much of the performance and personnel (e.g., aptitude and training) data were generated by subject matter experts. The hypothetical data were developed to support demonstrations of the analyses suggested by the methodology. Prior to this, there has been no across the board requirement for the collection of these data during Army test and evaluation programs.

The NAVSTAR GPS MANPACK AUE provides three dimensional position, velocity, and time as derived from signals of an eighteen satellite constellation. Figure\1-2 shows a drawing of the system. The MANPACK AUE is intended to determine position location of a user in three

dimensions to a spherical accuracy of 15 meters. Specific uses include weapon location, target and sensor location, coordination of firepower, scout and screening operations, combat resupply, location of obstacles, barriers, and gaps, and communications support. Velocity is intended to be accurate to .1 meter/second (RMS). System time is calculated to within .1 microsecond and displayed with a one second resolution. Life expectancy of the set is fifteen years. Weight of the set is seventeen pounds. (Reference: modified from NAVSTAR global positioning system Basis of Issue Plan (BOIP), dated: 11 October 1985).

The NAVSTAR GPS MANPACK AUE will be used throughout the remainder of this handbook to illustrate the methodology.

SS-US-200 CONCEPT OF "SYSTEM" EFFECTIVENESS

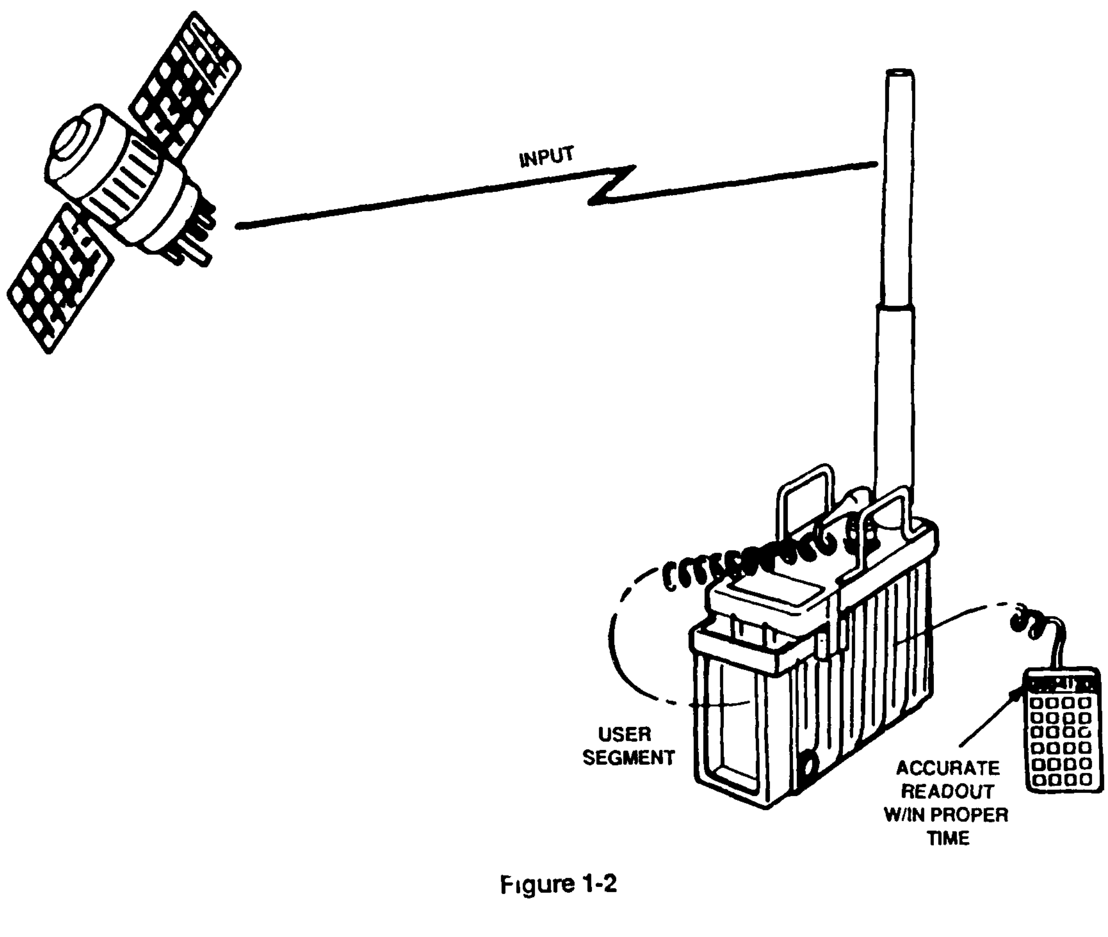

Figure 1-2

II. MANPRINT SYSTEM EFFECTIVENESS

System effectiveness is defined as the extent to which the system carries out its stated mission given that the system is in an appropriate operating condition at the outset of a mission. The measures used to evaluate system effectiveness depend upon the specific system being evaluated and its intended mission(s). In many cases, multiple measures of system effectiveness may be needed for a specific system, particularly if it carries out different missions.

In general, measures of system effectiveness will be probability type measures -- e.g., probability of mission success; the probability of killing a target, probability of detection, execution, and transfer; probability of arriving at correct location; probability of threat identification.

The basic system effectiveness model is depicted in Figure 2-1. As shown in the figure MANPRINT system effectiveness can be decomposed into functions and subfunctions. These functions and subfunctions can be performed by either soldier or materiel, or both. For the purpose of evaluating $E_{MANPRINT}$, system effectiveness is decomposed to a level necessary to identify all critical soldier functions or tasks. These soldier tasks can then be collected together so that overall soldier performance ($P_{soldier}$) is defined as the probability that the soldier successfully performs all critical tasks on a mission:

$$P_{Soldier} = (P_{task\ 1})(P_{task\ 2})(\ldots)(P_{task\ n}).$$

The materiel functions can likewise be collected to define materiel performance ($P_{Materiel}$) as the probability that the materiel successfully performs all critical functions during a mission:

$$P_{Materiel} = (P_{Materiel\ Function1})(P_{Materiel\ Function\ 2}) \ldots (P_{Materiel\ Function\ n})$$

MANPRINT system effectiveness is then defined as the product of overall soldier performance and materiel performance:

$$E_{MANPRINT} = (P_{Soldier})(P_{Materiel})$$

The steps in accomplishing the evaluation and analysis of MANPRINT system effectiveness are: 1) planning, 2) evaluation, and 3) analysis. Each step is described in detail in the following paragraphs.

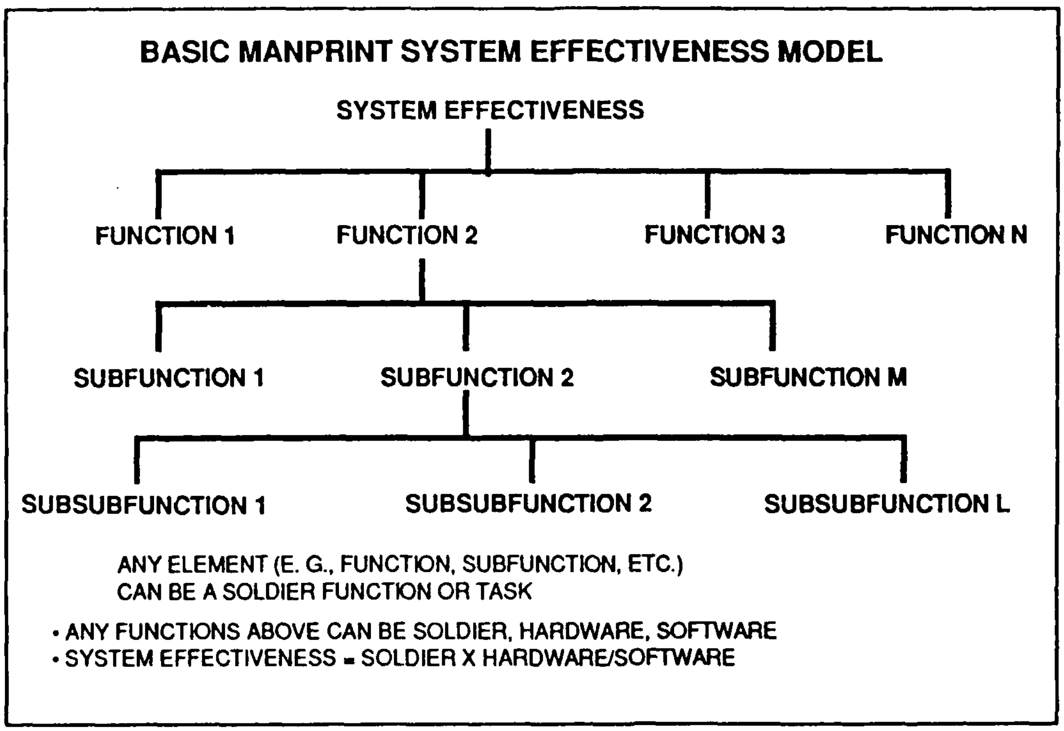

Figure 2-1

Planning the evaluation and analysis of MANPRINT system effectiveness

Development of MANPRINT Effectiveness Issues

The current policy of the Army with regard to the development of any (not just MANPRINT) test and evaluation issues and criteria[1] is:

Only those critical mission effectiveness issues and criteria will be addressed. Analysis of the operational missions will define those primary and secondary mission functions requiring testing and evaluation to determine readiness for production and fielding.

Mission effectiveness issues and criteria developed will apply to the total system operating in the field environment. Evaluation of RAM, Logistics, Training, Organization, Doctrine/Tactics/Techniques, Human Factors/Safety, ...will be part of mission effectiveness assessment without need for separate issues and criteria.

Criteria statements should reflect probability of successfully accomplishing the specific mission functions.

Initial issues and criteria will be developed concurrently with the Operational and Organizational (O&O) plan.

MANPRINT system effectiveness incorporates soldier and materiel performance into an integrated measure of effectiveness. Therefore, MANPRINT issues and criteria are part of mission effectiveness without the need to develop MANPRINT issues which stand apart from mission requirements of the system.

As described above the MANPRINT Effectiveness model incorporates both soldier and materiel performance. This handbook addresses only how to develop the soldier performance measure. This consists primarily of identifying the critical soldier tasks that are included in the overall measure of soldier performance, and of defining successful task completion for each.

Selection and Definition of Critical Soldier Tasks

Critical soldier tasks are those which, if not performed in accordance with system requirements, will most likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety (MIL-H-46855B, Human Engineering Requirements for Military Systems, Equipment and Facilities). Critical tasks, as discussed in MIL-H-46855, often consist of a "single" line or flow in the operation or maintenance cycle of the system which if not performed correctly may preclude mission attainment (e.g., a garbled or omitted transmission to prepare a missile for launching may preclude the entire missile operation).

Soldier tasks also are considered critical whenever equipment design characteristics impose demands which exceed human capabilities or seriously limit human performance. Critical soldier tasks may be evident under some of the following circumstances:

- human performance functions and tasks too demanding (e.g., exceed performance times).
- information presented to personnel inadequate to meet subsequent performance requirements.
- difficulty in perceiving displayed information.
- inability to operate controls efficiently.
- damage to or degradation of system equipment below reliabiliy requirements.
- injury to personnel.
- breach of weapon system security.

The above circumstances can be summarized and subsumed under one of

[1] Communication from: Commander, U. S. Army Training and Doctrine Command, Ft. Monroe, VA, dated: December 1985. Subject: Development and Approval of Test and Evaluation Issues and Criteria.

the following three general critical task classes which the tester can employ for determining whether a soldier task is critical.

- Tasks which can lead to operational mission failure.

- Tasks which can lead to injury to personnel.

- Tasks which can lead to damage to equipment.

Sources of data to identify critical soldier tasks are numerous. To enhance the relationship between operator tasks performed in the job or field situation and those performed during testing, the tester should collect as complete a set of task data as is possible. Listed below are some sources to which the tester will have access (especially for developmental or similar predecessor systems).

- Formal System Task Listings and Task Analysis Worksheets.

- Operator's manuals and procedures.

- Logistic Support Analysis Records (LSAR)

- Subject Matter Expert Communication.

- Programs of Instruction.

- Equipment Descriptions, Engineering Drawings and Specifications.

Listed below are desirable characteristics of task statements in the event that the tester will have to add to existing system task lists.

- A task statement is a statement of a specific action. The statement has a verb and object (e.g., inspect exhaust system).

- A task has a definite beginning and end.

- Tasks are performed in relatively short periods of time (i.e., seconds, minutes, or hours, but rarely, if ever, days, weeks or longer).

- Tasks must be observable so that their occurrence is readily determinable.

- A task must be measurable so that the tester will be able to conclude whether or not the task was performed correctly. A performance standard must be identified.

- Each task is independent of other actions. Each task statement must describe a finite and independent part of the job.

Properly phrased task statements will serve to make the tester's job easier. For example, for tasks that have a time sensitive standard, the tester will know readily when to start the timing interval if the task statement has a definite beginning or onset.

Performance standards, because of their importance, deserve careful consideration. Performance standards refer to how well a task must be performed in the real world environment. They represent a minimum acceptable level or quality of task performance. Performance standards are typically defined in terms of:

- Time (i.e., task performed within specified time period).

- Accuracy (i.e., task performed within prescribed tolerances or number of errors).

- Completion of step sequences.

An example of a task statement and associated performance standard (for a tank driver) is provided below.

TASK STATEMENT:	Move M1 tank to alternate position.
PERFORMANCE STANDARD:	within 5 minutes.
START TIME:	Command from Tank Commander "Seek Alternate Position."
STOP TIME:	Statement from Driver "Alternate Position Occupied."

Originally, task statements and performance standards are derived from either system requirements, from panels of experts with experience in performing or supervising the tasks, or from actual job performance data collected by direct observation. The basic goal is to start with a measure that is as identical as possible to the task it is intended to measure and then make modifications that are dictated by testing constraints. The following testing constraints, which will influence the direction and nature of the test measures, need to be considered.

a. Time availability may be restricted so that it is impractical to test the task under the same conditions that exist in the real world environment. However, if the soldier performance in question is a function of elapsed time (e.g., maintaining vigilance on a radar scope), the tester should not be so accommodating to compromises involving time.

b. Test participant availability can impose practical constraints. Once again, however, if the task under evaluation is manpower intensive, the tester needs to be very cautious about compromising the test because of insufficient test participants.

c. Cost is another important factor in measuring soldier performance. The cost of test administration must be kept within the limits dictated by the test budget of the sponsoring organizations. (If the mission called for demolishing a bridge with a new telemetric device, the tester would do well to find a less costly option than to blow up the bridge.)

d. Sufficient facilities or specialized equipment may not be available for test administration. An extreme example of a facility-caused constraint is firing a missile downrange when the range is truncated or too small. A more common example might be troubleshooting a computer when the downtime of the computer may cause such an inconvenience to other users as to negate its use for testing purposes.

Other constraints that occur during testing and that will alter what can be measured include logistics, safety, communications, environmental, ethical and privacy act considerations.

Data requirements.

The basic data required for the MANPRINT Effectiveness model are counts of the number of times each task is successfully and unsuccessfully performed. The appendix to this handbook provides example forms for the collection of these data, as well as additional forms for aggregating data from individual soldiers.

Additional qualitative data should also be collected to assist in diagnosing reasons for poor performance. These data may include: critical incident reports, self-report questionnaires, interview records, and observer checklists of soldier performance. The objective is to develop a descriptive data base of soldier performance which describes performance and human factors problems for each critical operator task.

Evaluation

This section presents the basic analysis procedures for computing the soldier performance parameters used in the MANPRINT system effectiveness model and the procedures for then computing MANPRINT system effectiveness. Separate analyses should be performed for different test conditions. For example, if testing is performed in both daytime and at night, a separate analysis would be performed for each condition.

To calculate MANPRINT system effectiveness and the effect of soldier performance on system effectiveness involves two phases: (1) estimation of soldier performance parameters for critical tasks and (2) calculation of MANPRINT system effectiveness. Each phase is described below.

Soldier Performance.

Soldier performance on critical tasks is based on data collected as described in the previous paragraphs. For each critical task data should be analyzed using the following steps.

1. Complete the Summaries of Operator Performance Data for Individual Soldiers and the Summaries of Operator Performance for System Effectiveness as described in the instructions for these worksheets in the Appendix. This will provide a probability of success estimate for each critical task on the Summary of Operator Performance for System Effectiveness worksheet.

2. Multiply these probabilities of success together to obtain an overall soldier performance parameter.

The following steps are optional. They may be performed to provide a more in-depth analysis of soldier performance and to determine the sensitivity of soldier performance parameters and system effectiveness to the time it takes soldiers to perform the critical tasks. In these steps, rather than using data indicating only whether a critical task was successfully performed without regard to time, performance time standards are established (and varied) so that a task is "successfully" performed only if it is completed within a specified time.

3. Use the Operator Performance Worksheets to determine the range of task completion times.

4. Determine whether doctrine, tactics, system requirements, etc. indicate any time limits on task completion time. If so, use these limits in the subsequent steps.

5. If no limits are identified in step 4, establish arbitrary limits covering the range of task completion times. To avoid excessive analysis time probably no more than two limits should be used unless the data base is computerized and the subsequent steps are performed with existing software.

6. For each completion time limit, use the Soldier Performance Worksheets to determine for each task trial if the task was successfully completed (item II.1) and was completed in less than the time limit (item II.2). For the purpose of this optional analysis, a task is defined as being successfully completed only if both of these criteria are met.

7. Complete the two types of summary forms (as in step1 above) using the data obtained in step 6.

System effectiveness.

MANPRINT effectiveness is calculated using

$$E_{MANPRINT} = (P_{soldier})(P_{materiel}) \ .$$

The above steps provide (Psoldier). (Pmateriel) should be available from other test data. The sensitivity of system effectiveness to limitations on task completion times can be determined by using data from steps 3-7 rather than data from step 2 in determining the overall soldier performance measure.

Analysis

The analysis phase of the quantitative MANPRINT methodology can be used to accomplish several objectives:

- to determine which MANPRINT factors (i.e., manpower, personnel, training, human factors engineering, system safety, and health hazards) affect system effectiveness through which soldier tasks;
- to determine how much system effectiveness is affected; and to evaluate possible solutions.

In general, analysis will address two types of issues: (1) those identified prior to testing as MANPRINT issues (e.g., is the mental aptitude required to operate the system higher than that which will generally be available in the operator population?) and (2) those identified in the evaluation phase (e.g., system effectiveness is relatively low primarily because of poor soldier performance on one task, so what fixes can be made?).

The analysis procedures are basically of two types. Each accomplishes the same purpose but is appropriate for different types of data. Several examples of analyses are provided in Section 4 of this handbook.

The first type of analysis is categorical

analysis. In this analysis performance data are divided into categories of the MANPRINT variable of interest. These variables could include mental categories, MOS, human factors engineering designs, health or safety hazards or lack of the hazard. For example with two human factors engineering designs, soldier performance would be measured in two categories -- one for each design. These performance estimates would then be compared, as would system effectiveness, to evaluate the alternative designs.

The analysis is composed basically of the following steps (as illustrated in detail in Section 4):

- Identify the MANPRINT variable(s) of interest (e.g., aptitude, system design, training, etc.) and the appropriate categories of the variable (e.g., mental categories, alternative designs, MOS).

- Identify the soldier performance variables of interest, e.g., specific task success probability(ies) or overall soldier performance probability ($P_{soldier}$).

- Set up a table that shows the soldier performance value for each category and the overall system effectiveness for each category. (In effect, this is simply completing the evaluation phase described above once for each category of data rather than once for all data.)

- Make appropriate comparisons between soldier performance and system effectiveness among categories.

(optional)

- In some instances, additional analysis will be appropriate and useful. In particular if the categories are characteristics of soldiers (e.g., mental category) rather than of systems (e.g., different designs), it may be desirable to generalize from the available data to other populations of soldiers, either real or hypothetical. For example, as is illustrated in the second analysis example in Section IV, categorical soldier performance data for mental categories can be used to predict the performance of operator populations with varying distributions of mental categories and therefore the system effectiveness that could be achieved by varying operator aptitude requirements.

The second type of analysis is linear regression. Linear regression is a statistical technique that predicts the value of one variable (e.g., soldier performance) based on knowledge of the value of a second variable (e.g., aptitude). Both variables must be measured on continuous, quantitative scales. Formulas for computing linear regression are found in any introductory statistics textbook, and all statistical software programs perform linear regressions. The result of a linear regression analysis is a model:

$$Y = bX + a$$

where Y is the variable being predicted, (e.g., soldier performance), X is the known value of the variable used to predict (e.g., aptitude), and b and a are constants that are derived statistically from the data in the linear regression analysis. With such a model, the performance of a soldier or the average performance of a group of soldiers can be predicted from the aptitude of the soldier or the average aptitude of the group of soldiers.

The steps in performing the linear regression analysis are essentially the same as those for categorical analysis except the computation of the linear regression in step 3 is not for categories and requires software or a computation formula from a statistics text.

In addition to those two types of analyses which are quantitative, the analysis phase also makes great use of qualitative data to assist in diagnosing causes of poor performance and/or possible solutions. Qualitative data are particularly useful in analyses relating to human factors engineering, system safety, and health hazards. In the latter two areas the quantitative analyses described above only determine the extent to which safety and health hazards affect soldier performance and system effectiveness. They do not address long term health effects on soldiers or the direct impact of hazards on the well-being of the soldiers.

System Effectiveness Example: MANPACK AUE of the NAVSTAR GPS

Using the approach to developing a MANPRINT Effectiveness model described above, the model for MANPACK AUE consists of the overall soldier performance (Psoldier) and the probability of success of three materiel functions:

• the probability of the AUE acquiring the minimum number (3) of satellites from the NAVSTAR constellation ($P_{satellite\ acquisition}$),

• the probability of the minimum number (3) of satellites accurately communicating with the AUE, ($P_{satellites\ communication}$), and

• the probability of AUE accurate interpretation of position (given correct initialization of AUE by operator), ($P_{AUE\ position}$).

There are four critical tasks associated with the probability of successful operation of the MANPACK AUE by current Army soldiers. The relationship of soldier performance to system performance of the MANPACK AUE is depicted in Figure 2-2. These four critical tasks are:

1. Operator (MOS General Purpose User (GPU)) initializes the MANPACK/Vehicular user equipment in accordance with procedures.

2. Operator uses AUE to determine current position and next waypoint with a specified degree of accuracy.

3. Operator determines that the MANPACK AUE is operating within specified operating limits when determining current position or next waypoint.

4. Operator replaces lithium battery safely and without damage to equipment.

The MANPACK initialization task is the most difficult of the four operator tasks and is described in greater detail in the following paragraphs.

In the case of the MANPACK AUE, operator initialization of the set involves the following steps:

MANPRINT CONCEPT OF "SYSTEM" EFFECTIVENESS

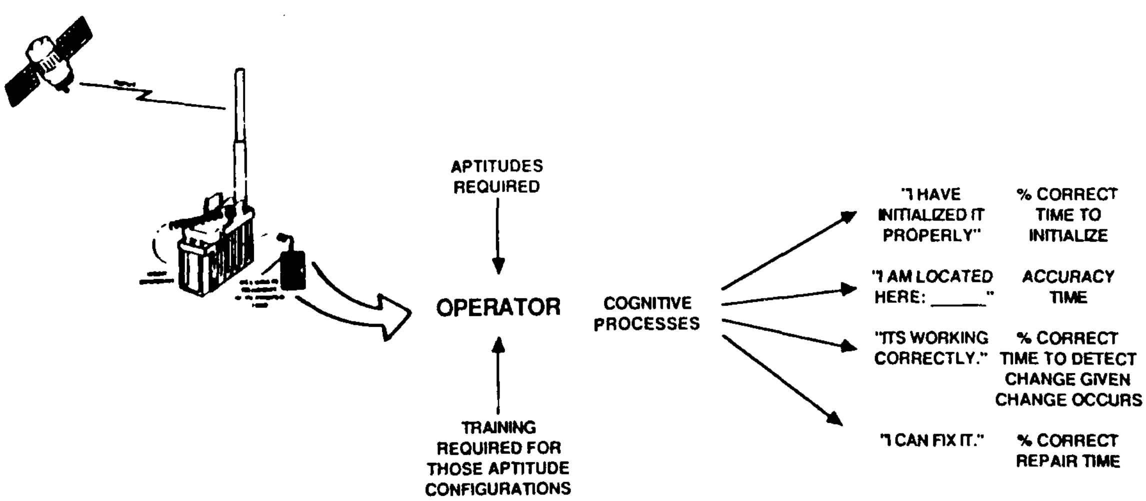

Figure 2-2

• Set start-up (which contains 20 different steps according to the operator manual);

• Set orientation (which contains 25 different steps according to the operator manual); and

• Checking and entering magnetic variation and map datum (which contains16 different map reading and equipment-related steps according to the operator manual).

Once these steps are successfully accomplished, the set will be keyed to the map the operator is using and provide the operator with accurate position information for use with a map. (This of course assumes that the operator continues to operate the equipment accurately and the equipment responds accurately.)

Operator initialization of the set requires the operator to enter the following data:

• set position in Military Grid Reference System (MGRS) coordinates or latitude/longitude;

• elevation;

• map's datum (in a coded number) and map declination (to establish magnetic variation); and

• zulu time (and local time).

Task 2 will change somewhat under EW or other degraded conditions. Other tasks will not change under these conditions. Therefore, performance under these conditions on task 2 will also be considered.

Operator Performance Measures.

For each critical task shown in the previous section above there are two soldier performance measures:

1. Critical task: initialize.

• Measures:

- % initialization correctly completed over trials
- time to initialize

2. Critical task: positioning and next waypoint determination.

• Measures:

- % determinations within specified accuracy
- time

2(a). Critical task: positioning and next waypoint determination in a degraded environment

• Measures:

- % determinations within specified accuracy
- time

3. Critical task: determines equipment status

• Measures:

- % correct over trials
- *time to detect change given change occurs*

4. Critical task: battery replacement

• Measures:

- % correct over trials
- replacement time

Qualitative human factors, training, safety, and health hazards data will also be collected for each critical operator task using observational checklists, surveys, questionnaires, and interview forms, as appropriate. All evaluation data will be maintained separately for each critical operator task to support later analyses.

System effectiveness model for MANPACK AUE

The system effectiveness analysis used for the MANPACK AUE included the use of operator performance probabilities for successful critical task performance as the basis for developing a measure of the contribution of soldier performance to the equation for MANPACK AUE system

effectiveness ($E_{MANPRINT}$).

System performance for the MANPACK AUE is important under two conditions: normal and degraded. Therefore two measures of MANPRINT effectiveness were derived with soldier performance ($P_{soldier}$) varying with the condition. Only performance of the position location task will change in the degraded condition. Soldier performance under normal conditions is:

s

$$P_{soldier} = (P_i)(P_{pl})(P_{fs})(P_r),$$

where,

$P_{soldier}$ = the probability of successful <u>soldier</u> performance,

P_i = the probability of successful <u>initialization</u> of the Manpack/Vehicular user equipment by the MOS GPU, (assuming the equipment is in an operable condition),

P_{pl} = the probability of the <u>location</u> of current <u>position</u> and next waypoint with the AUE with the degree of accuracy specified (given that the operator has not identified a failure status),

P_{fs} = the probability of identifying a <u>failure status</u> when a failure occurs, and

P_r = the probability of correct battery <u>replacement</u> when required.

Under degraded conditions, soldier performance ($P'_{soldier}$) is:

$$P'_{soldier} = (P_i)(P_{ld})(P_{fs})(P_r),$$

where,

$P'_{soldier}$ = the probability of acceptable soldier performance in a degraded environment,

P_i = the probability of successful <u>initialization</u> of the Manpack/Vehicular user equipment by the MOS GPU, (assuming the equipment is in an operable condition),

P_{ld} = the probability of position <u>location</u> in a <u>degraded</u> environment

P_{fs} = the probability of identifying a <u>failure status</u> when a failure occurs, and

P_r = the probability of correct battery <u>replacement</u> when required.

These soldier performance metrics ($P_{soldier}$ and $P'_{soldier}$) will be used as parameters in the MANPRINT system effectiveness ($E_{MANPRINT}$) models for the MANPACK AUE. Table 2-1 shows the task success probabilities for individual soldiers and the means of these probabilities which are used to compute $P_{soldier}$ = .58 under normal conditions. Under degraded conditions, the probabilities in the P_{pl} column (position location under normal conditions) become P_{ld} (position location in degraded environment). The mean value of P_{ld} is .86 resulting in a $P'_{soldier}$ of

SOLDIER PERFORMANCE PROBABILITY DATA
Table 2-1

Soldier	P_i	x P_{pl}	x P_{fs}	x P_r	= P_s
02	.42	.90	.92	1.00	.35
04	.55	.96	.94	1.00	.50
07	1.00	1.00	1.00	1.00	1.00
10	.60	.86	.72	1.00	.37
11	.96	1.00	.82	1.00	.79
12	.91	.96	1.00	1.00	.87
13	.72	1.00	.78	1.00	.56
14	.84	.92	.76	1.00	.59
32	.51	1.00	.94	1.00	.48
42	.49	.90	.82	1.00	.36
mean	.70	.95	.87	1.00	.58

$P'soldier = (.70)(.86)(.87)(1.00) = .52$.

The MANPRINT effectiveness model for the MANPACK AUE under normal conditions is:

$$E_{MANPRINT} = (P_s)(P_{as})(P_{sc})(P_{ep}) = (.58)(.90)(.93)(.95) = .46$$

where,

$E_{MANPRINT}$ = probability of position location within 15 meters of true position (MANPRINT effectiveness),

P_s = the probability of successful soldier performance

P_{as} = the probability of the user equipment acquiring the minimum number (3) of satellites from the NAVSTAR constellation,

P_{sc} = the probability of the minimum number (3) satellites accurately communicating with the user equipment, and

P_{ep} = the probability of user equipment accurate interpretation of position (given correct initialization of user equipment by operator).

Under degraded conditions MANPRINT effectiveness is:

$$E_{MANPRINT} = (P'_s)(P'_{as})(P'_{sc})(P_{ep}) = (.52)(.85)(.82)(.95) = .34$$

where,

$E_{MANPRINT}$ = the probability of position location within 15 meters of true position in a degraded environment,

P'_s = the probability of successful soldier performance in a degraded environment,

P'_{as} = the probability of the user equipment acquiring the minimum number (3) of satellites from the NAVSTAR constellation in a degraded environment,

P'_{sc} = the probability of the minimum number (3) satellites accurately communicating with the user equipment in a degraded environment, and

P_{ep} = the probability of user equipment accurate interpretation of position (given correct initialization of user equipment by operator).

III. MANPRINT AVAILABILITY

MANPRINT Availability (^{A}MANPRINT) is a percentage measure of the degree to which an item ofequipment is in an operable and committable state at the start of a mission, when: a) the mission is called for at an unknown point in time, and b) the mission incorporates soldier performance of corrective and preventive maintenance tasks under a given set of conditions. Figure3-1 modified from TRADOC Pamphlet 71-15, RAM Rationale Annex Handbook, shows the components of time used in defining the components of ^{A}MANPRINT.

With respect to ^{A}MANPRINT the system is considered to be capable of operating in two ways: 1) in actual use by Army personnel, and 2) capable of being used by Army personnel. The combination of 1 as measured by operating time (OT) and 2 as measured by operable standby time (ST_o) is termed 'uptime.' The term describing the time in which the system is not capable of operating is 'downtime.' Uptime plus downtime is total time. ^{A}MANPRINT is the ratio of uptime to total time. ^{A}MANPRINT is a measure of the likelihood that the system will function when called upon in a typical operating environment. Function depends upon the degree to which maintenance adequately supports the system. For the purpose of MANPRINT, the interest is in measuring the effect of soldier performance on ^{A}MANPRINT through performance of maintenance activities which occur during system downtime. There are four components of downtime. The first is total administrative and logistic downtime (TALDT), and is defined as downtime spent waiting for parts, maintenance personnel, or transportation. This component of downtime is a result of Army policy and organization and is not addressed as a MANPRINT issue during testing. Therefore, for purposes of MANPRINT, TALDT is assumed to be given. The second component is inoperable standby time (ST_i), which is defined as downtime produced when the system is reported to be capable of operating following maintenance but is in fact inoperable. For the purpose of MANPRINT, this occurs when maintenance activities a) fail to restore the system to an operable status, and b) this failure is not recognized by maintenance personnel. This component does not include false acceptance by test equipment when operated appropriately

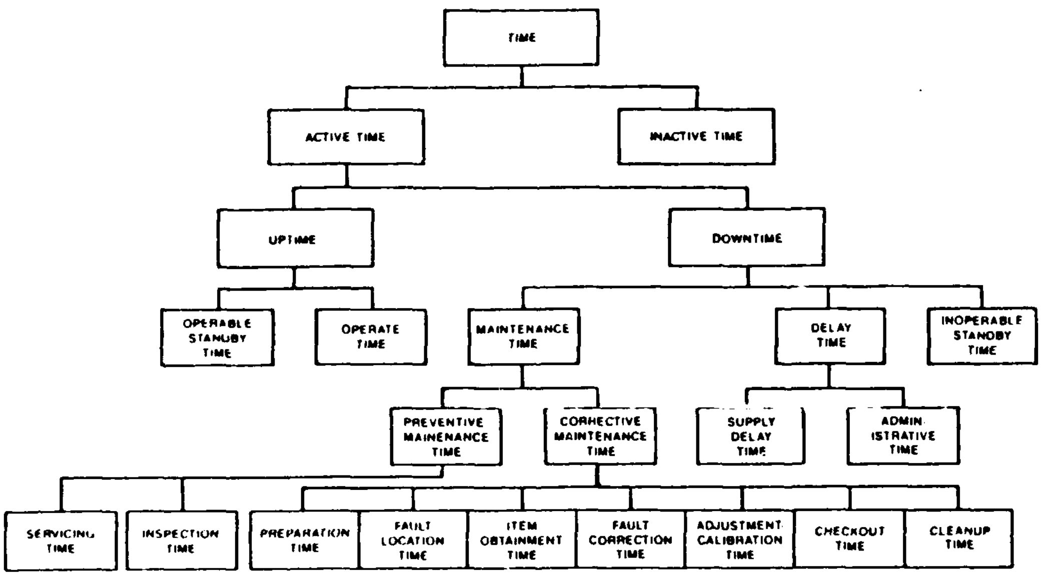

Figure 3-1 Operational Time Tree

by maintenance personnel. The third component of downtime is total preventive maintenance time (TPM), which is scheduled on a routine basis. The fourth component is total corrective maintenance time (TCM), which is unplanned maintenance to restore the system to an operable status following a failure. This includes any additional maintenance time required to correct errors identified prior to completion of the maintenance activity. The last three components of downtime (ST_i, TPM, and TCM) are affected by soldier performance of maintenance activities and are of interest to MANPRINT.

The equation for measuring ^{A}M is shown in Figure 3-2:

where:

- Operating time (OT) is the operating time during a given time period,

- Standby time (ST) is the total time the system is not operating or being maintained, (this measure is calculated solely to calculate operable and inoperable standby time),

- Operable standby time (STo) is the time the system is operable but not being operated or maintained,

- Inoperable standby time (STi) is the time the system is inoperable but presumed operable,

- Total corrective maintenance (TCM) time is the time the system is being repaired following a failure,

- Total preventive maintenance (TPM) time is the time the system is being maintained for periodic maintenance (not including maintenance of a failed item), and

- Total administrative and logistic downtime (TALDT) is the time the system is waiting for maintenance (either corrective or preventive) but is not actually being maintained (e.g., waiting for parts or maintenance personnel.)

$$A_{MANPRINT} = \frac{\text{Operating Time (OT)} + \text{Operable Standby Time } (ST_o)}{OT + ST_o + \begin{array}{c}\text{Inoperable}\\\text{Standby}\\\text{Time}\\(ST_i)\end{array} + \begin{array}{c}\text{Total}\\\text{Correct-}\\\text{ive}\\\text{Maint-}\\\text{enance}\\\text{Time}\\\text{(TCM)}\end{array} + \begin{array}{c}\text{Total}\\\text{Preven-}\\\text{tive}\\\text{Mainten-}\\\text{ance}\\\text{Time}\\\text{(TPM)}\end{array} + \begin{array}{c}\text{Total}\\\text{Adminis-}\\\text{trative}\\\text{and}\\\text{Logistic}\\\text{Downtime}\\\text{(TALDT)}\end{array}}$$

or in short hand notation:

$$A_{MANPRINT} = \frac{OT + ST_o}{OT + ST_o + ST_i + TCM + TPM + TALDT}$$

Figure 3-2

In order to measure the effect of soldier performance of maintenance activities on AMANPRINT, the components of downtime relevant to MANPRINT issues have to be decomposed. Operable standby time needs to be distinguished from inoperable standby time because soldier errors during maintenance may not be identified prior to the next operation of the system. The inoperable standby time should be considered downtime (produced through soldier performance) as opposed to uptime.

The decomposition of TCM and TPM is described in the following two sections.

<u>Planning the Evaluation and Analysis of MANPRINT Availability</u>

Identify Critical Items of Equipment, Failure Mode and Maintenance Tasks

For purposes of this document, critical items of equipment refer to those items of equipment, which if unavailable, would lead to operational mission failure or degraded mission performance. The tester should start this phase of activity by gathering relevant data sources. Good sources of information for items of critical equipment include:

- Logistics Support Analysis Record (LSAR; Data Sheets A, B, C, D, & D1)

- Failure Mode and Effect Analysis (FMEA)

The LSAR serves as a means for the collection, acceptance, storage, manipulation and retrieval of maintenance analysis data. Data Sheet B should be especially helpful in terms of the type of failure data, including failure modes, effects, and frequency, that it provides. The FMEA, on the other hand, examines all potential failure modes and their causes in order to assess the *reliability status* of the various items and the effect of each failure mode on operation.

Develop Critical Equipment List

Upon compilation of data that are accurate and relatively complete, the tester will need to develop a *critical items of equipment list*. The list of items of critical equipment should be organized by test issues upon which they are likely to impact. The relationship of critical items of equipment to failure modes and maintenance tasks is shown in Figure 3-2.

Once a list of equipment is established, the tester may find it convenient to code each item by one of the following categories:

- Unavailability would lead to operational mission failure

. DECOMPOSED MODEL FOR TCM:

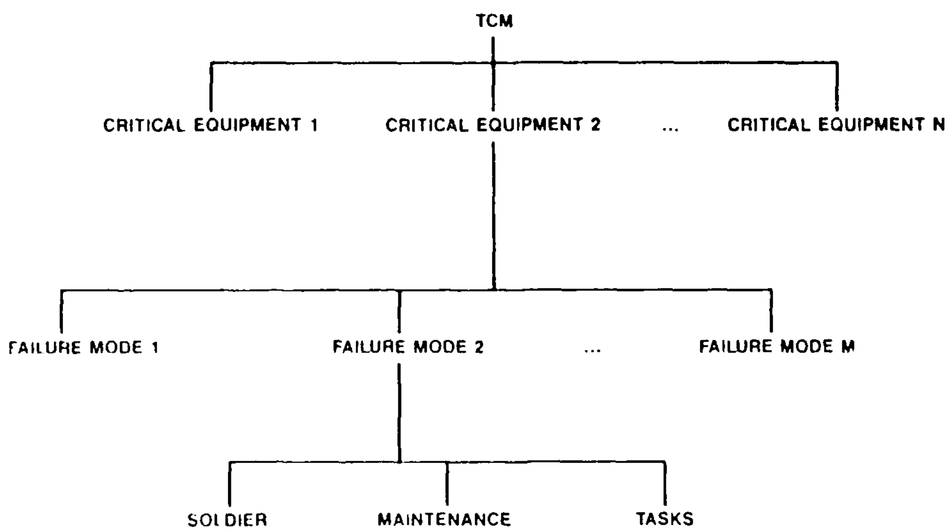

Figure 3-3

• Unavailability would result in degraded mission performance and/or safety, health hazard

• Unavailability would have no impact on mission

Determine Failure Modes by Critical Items of Equipment

At this point, the tester needs to gain an understanding of the potential failure modes associated with each item of critical equipment. The potential failure modes can be identified from the LSAR and FMEA data sources. To ensure the accuracy or completeness of the information, the tester may need to enlist the aid of a subject matter expert.

Determine Which Maintenance Tasks are Performed by Maintainers

Critical soldier corrective maintenance tasks are those maintenance activities that must be performed to correct failures of critical items of equipment. That is, if the equipment is essential to accomplishment of the mission, then corrective maintenance of that equipment is critical. Seven generic corrective maintenance tasks have been defined (Reference: TRADOC/DARCOM Pamphlet 70-11, RAM Rationale Annex Handbook, July 1982), each of which may or may not be included in corrective maintenance of critical equipment. These maintenance tasks are:

Preparation (for maintenance)
Fault location
Item obtainment
Fault correction
Adjustment/calibration
Checkout
Cleanup

Determine Types of Preventive Maintenance

The tester will need to identify the types of preventive maintenance for which preventive maintenance data should be collected. The list should include types of preventive maintenance that could lead to an operational mission failure, safety problem or health hazard to soldiers, if not accomplished properly. Critical soldier preventive maintenance tasks are those maintenance tasks required to be performed often enough to have some effect on AMANPRINT given a reasonable range of maintenance times.

Determine Qualitative Data Requirements for Maintenance

The tester should identify the human factors, safety, training, and health hazards data requirements for use in diagnosing the contribution of soldier performance to system availability. The major requirement of these data is that it is relatable to critical items of equipment, failure types/modes for each item of equipment, and maintenance tasks performed for each failure type. The data may include the following: critical incident reports, self-report questionnaires, interview records, and observer checklists of maintainer performance. The objective is to develop a descriptive data base of maintenance performance which describes soldier performance problems for each critical item of equipment, failure type/mode, and maintenance task.

<u>Evaluation of MANPRINT Availability</u>

The evaluation uses the equation for MANPRINT Availability shown previously in Figure 3-2. The approach to conducting the evaluation consists of the following steps.

Step (1) Complete all the maintenance worksheets.

Step (2) Calculate Operating Time (OT) by adding all the time the system is operating during the measurement period.

Step (3) Create a worksheet for corrective maintenance such as shown in Figure 3-4, entering data line by line as described in the following steps.

Step (4) For each piece of critical equipment and each failure mode enter the average times for each

TOTAL CORRECTIVE MAINTENANCE (TCM) TIME WORKSHEET

CRITICAL EQUIPMENT (I)	FAILURE MODE (J)	MINUTES							HOURS CMij	Fij	(Fij)(CMij)	TCMi
		PT	FLT	IOT	FCT	ACT	CT	CUT				

TCM= ____

PT=Preparation Time
FLT=Fault Location Time
IOT=Item Obtainment Time
FCT=Fault Correction Time
ACT=Adjustment Calibration Time
CT=Checkout Time
CUT=Cleanup Time

Figure 3-4

maintenance task from the Summary of Corrective Maintenance for System Availability worksheets.

Step (5) For each piece of critical equipment and each failure mode, obtain the failure rate, f, and enter it. These failure rates should be available from RAM data. It is important that each rate have comparable limits of time, e.g., per day, per month, etc. If available failure rates are measured in units other than time, e.g., per hour of operation, per round fired, per mile driven, per mission performed, etc., these rates must be transformed into rates with time units by determining the usage rate, for example, the hours of operation per unit time. The parameter f is then determined by multiplying the failure rate in non-time units by the usage rate: f (measured in failures/unit time) = failures/non-time unit x (number of non-time units/unit time).

Step (6) In the CMij column, enter the sum of the entries in columns PT through CUT for the seven maintenance tasks.

Step (7) In the (Fij)(CMij) column, enter the product of f and CMij, the two preceding columns.

Step (8) For each piece of critical equipment, sum the (Fij)(CMij) entries over all failure modes and enter this sum in the TCMi column (one entry for each piece of critical equipment).

Step (9) After the above steps have been completed for all equipment and failure modes, total corrective maintenance time, TCM, can be computed by summing TCMi over all pieces of critical equipment. The result can

be entered in the bottom right side of the worksheet.

Step (10) Create a worksheet for preventive maintenance such as shown in figure 3-5, entering data line by line as described in the following steps.

Step (11) For each type of maintenance, enter the average completion time from the Summary of Preventive Maintenance for System Availability worksheets.

Step (12) Determine the frequency required for each type of preventive maintenance, and enter this value in the r column. Again, all rates must be in comparable units of time, e.g., days, months, etc. -- the same time units used for failure rates for corrective maintenance. (See step 4 for further discussion of how to determine these rates.)

Step (13) In the (PMT)(r) column, enter the product of the PMT and r columns.

Step (14) To compute total preventive maintenance, sum the values in the (PMT)(r) column,

Step (15) TALDT is provided by the combat developer (U.S. Army Training and Doctrine Command).

Following any type of maintenance, there is some probability that the system is not restored to an operable status and this failure is not recognized. (To simplify, this probability will be referred to as "maintenance failure probability"). These probabilities can be different for the various types of maintenance performed. In particular, the probability for corrective maintenance can vary for each failure mode for each critical item of equipment and by type for preventive maintenance. To determine the overall maintenance failure probability requires averaging the maintenance failure probabilities for both corrective and preventive maintenance with each weighted by its rate of occurrence.

TOTAL PREVENTIVE MAINTENANCE (TPM) TIME WORKSHEET

TYPE OF MAINTENANCE (k)	PMT	RATE (r)	(PMT)(r)

PMT=Preventive Maintenance Time | TPM=

Figure 3-5

Both corrective and preventive maintenance are addressed in this logic.

Step (16) ST_o and ST_i are measured by:

a. calculating total standby time (ST), which is equal to total time minus OT, TCM, TPM, and TALDT,

b. calculating the probability (Pm) that the system is not restored to an operable status and that the failure is not recognized by maintenance personnel, where Pm is the weighted average of these probabilities for corrective maintenance on all failure modes for each critical item of equipment and for each type of preventive maintenance weighted by the rates. The weights used to average these probabilities are the frequencies with which they are performed. The MANPACK AUE example in the following subsection illustrates this computation.

c. calculating inoperable standby time:

$$ST_i = Pm\,(ST).$$

d. calculating operable standby time:

$$ST_o = ST - ST_i = (1 - Pm)(ST)$$

Step (17) Availability is then computed by

$$Am = \frac{OT + ST_o}{OT + ST_o + ST_i + TCM + TPM + TALDT}$$

where OT comes from step 2, TCM comes from step 9, TPM comes from step 14, TALDT comes from step 15, and ST_o and ST_i come from step 16.

Analysis of MANPRINT Availability

Analysis with respect to availability is similar to that for effectiveness. The only difference is in the soldier performance variables. For availability these variables may be:

- performance times for specific corrective maintenance tasks for particular critical equipment and failure mode
- performance times for total corrective maintenance for a particular critical equipment and failure mode;
- total corrective maintenance times;
- preventive maintenance times for a particular type of maintenance;
- total preventive maintenance times, and
- maintenance success probabilities.

Otherwise, analysis is as described for effectiveness and various examples are provided in the following Section.

__Example Evaluation of MANPRINT Availability: MANPACK AUE of the NAVSTAR GPS__

The MANPACK AUE has three critical items of equipment (as shown in Figure 1-2), including: the Control Display Unit (CDU), the Receiver Processor Unit (RPU), and the Antenna unit. The CDU has four failure modes: 1) keyboard failure, 2) LED failure, 3) cracked cable at CDU, and 4) failure in CDU due to moisture in display unit. The RPU has two failure modes: 1) BIT "Fail" displayed, and 2) loss of satellite acquisition. The antenna unit has two failure modes: 1) broken RF connector and 2) stripped threads on antenna base segment. Corrective maintenance is performed on each critical item of equipment for all failure modes, except: the adjustment/calibration task and the item obtainment task (for the moisture in display failure mode in the CDU). The only type of preventive maintenance is the CDU memory battery replacement. This preventive maintenance is conducted once every six months. The maintainers for the MANPACK AUE are MOS 31E and MOS 31V soldiers. The evaluation of $A_{MANPRINT}$ was conducted using the

equation shown in Figure 3-2 and step 17 above.

Total Corrective Maintenance (TCM).

Table 3-1 shows the summary data for Total Corrective Maintenance Time for the AUE. Each column in the Table is defined below.

1. Critical items of equipment.
2. Failure modes (different for each critical item of equipment).
3. Mean Preparation Time (PT) measured in test.
4. Mean Fault Location Time (FLT) measured in test.
5. Mean Item Obtainment Time (IOT) measured in test.
6. Mean Fault Correction Time (FCT) measured in test.
7. Mean Adjustment/Calibration Time (ACT) measured in test.
8. Mean Checkout Time (CT) measured in test.
9. Mean Cleanup Time (CUT) measured in test.
10. Mean Corrective Maintenance Time (CMij) for Failure mode j on critical item of equipment i, calculated as sum of columns 3 through 9.
11. Number of failures (Fij) for the given failure mode during test (total time = 4,478 hours).
12. Product of failure rate (Fij) times the mean corrective maintenance time (CMij) or total time for corrective maintenance for the given failure mode. Calculated by multiplying column 10 by column 11.
13. Total Corrective Maintenance Time (TCMi) for given critical item of equipment. Calculated by summing all rows for the given item in column 12.
14. Total Corrective Maintenance

Table 3-1 TOTAL CORRECTIVE MAINTENANCE (TCM) TIME WORKSHEET

CRITICAL EQUIPMENT (I)	FAILURE MODE (J)	MINUTES							HOURS CMij	Fij	(Fij)(CMij)	TCMi
		PT	FLT	IOT	FCT	ACT	CT	CUT				
CDU	KEYBOARD	1.54	2.82	12.75	20.63	N/A	30.99	.60	1.16	10	11.60	
	LED	.54	1.58	14.80	52.53	N/A	31.73	.58	1.70	8	13.60	
	CABLE	.53	1.10	15.84	13.04	N/A	30.99	.50	1.03	7	7.21	
	MOISTURE	.97	.10	N/A	40.03	N/A	31.98	.53	1.23	6	7.38	39.79
RPU	BIT	9.63	25.17	14.83	36.84	N/A	31.77	10.99	2.15	23	49.45	
	SAT. LOSS	9.75	34.45	12.78	43.94	N/A	31.13	10.93	2.38	25	59.50	108.95
ANTENNA	AF CONNECTOR	3.44	.53	7.17	15.54	N/A	30.16	1.56	.97	7	6.79	
	STRIPPED THREADS	.94	.48	20.22	5.76	N/A	30.03	.94	.97	7	6.79	13.58

TCM=

PT=Preparation Time
FLT=Fault Location Time
IOT=Item Obtainment Time
FCT=Fault Correction Time
ACT=Adjustment Calibration Time
CT=Checkout Time
CUT=Cleanup Time

(TCM) for the system calculated as sum of column 13.

As shown in the table, Total Corrective Maintenance (TCM) for the AUE was calculated to be 162.32 hours. This result will be used in the equation for computing ^{A}MANPRINT.

Total Preventive Maintenance (TPM). Table 3-2 shows the summary data for computing Total Preventive Maintenance (TPM). This worksheet is blank since a) there is only one critical type of preventive maintenance for the MANPACK AUE and b) that preventive maintenance task occurs too infrequently to make any difference in the results of the ^{A}MANPRINT evaluation. (This is not expected to happen in many systems other than the MANPACK AUE.) The preventive maintenance task is replacement of the CDU memory battery. Since it only occurs once every six months, this task has marginal impact on the calculation of ^{A}MANPRINT and can therefore be deleted. Each column in the worksheet is defined below.

1. Type of Maintenance is each of the various types of preventive maintenance that may be required.
2. Mean Preventive Maintenance Time (PMT) is the mean time to perform the required maintenance measured during testing or otherwise available.
3. Rate (r) for the identified type of preventive maintenance -- i.e., how often it is performed.
4. Mean Preventive Maintenance Time (PMT) multiplied by Rate (r) to provide a measure of total maintenance time for the identified type of maintenance in a given time period -- calculated as column 2 times column 3.
5. Total Preventive Maintenance Time (TPM) calculated as the sum of column 4.

As discussed above, the TPM for the MANPACK AUE was zero (0). This result will be used in the calculation of ^{A}MANPRINT.

Standby Time (ST). Table 3-3 shows the

TOTAL PREVENTIVE MAINTENANCE (TPM) TIME WORKSHEET
Table 3-2

TYPE OF MAINTENANCE (k)	PMT	RATE (r)	(Pm)(r)

PMT=Preventive Maintenance Time

TPM= 0

Table 3-3 STANDBY TIME (ST) WORKSHEET

TYPE OF MAINTENANCE				
CORRECTIVE				
CRITICAL EQUIPMENT	FAILURE MODE	Pm	RATE	PRODUCT (Pm x Rate)
CDU				
	KEYBOARD	.300	10	3.000
	LED	.625	8	5.000
	CABLE	.000	7	0.000
	MOISTURE	.000	6	0.000
RPU				
	BIT	.174	23	4.002
	SAT. LOSS	.385	25	9.625
ANTENNA				
	AF CONNECTOR	.143	7	1.001
	STRIPPED THREADS	.286	7	2.002
PREVENTIVE				
MEMORY BATTERY IN RPU		.040	1.02	0.041

Pm = .263
OVERALL ST = 3677
ST_i = (.263) (3677) = 968
ST_o = (.737) (3677) = 2709

summary data for computing ST. From ST both Operable Standby Time (ST_o) and Inoperable Standby Time (ST_i) will be calculated. Corrective maintenance and preventive maintenance data both are used in calculating ST. Each column in the worksheet is defined below.

1. Type of maintenance is the failure mode for each critical item of equipment for corrective maintenance and the type of maintenance for preventive maintenance. For the MANPACK AUE, this includes the three critical items of equipment (CDU, RPU, and Antenna Unit), associated failure modes, and the replacement of the memory battery for preventive maintenance.

2. Probability of Maintenance Failure (P_M) is the probability that the system is not restored to an operable status and that this failure is not recognized by maintenance personnel for the given type of maintenance measured during test.

3. Rate is the number of times the given type of maintenance is performed in a given time period. In this example the rates for corrective maintenance are for the total test time of 4,478 hours. The preventive maintenance rate is once every six months or 4,380 hours. This is equivalent to 1.02 times every 4,478 hours. <u>All rates must be for the same period of time.</u>

4. Product of the Probability of Maintenance Failure (P_M) times the Rate computed by multiplying column 2 by column 3.

5. Sum of Rates calculated as sum of column 3.

6. Sum of Products (P_M X Rates) calculated as sum of column 4.

7. Overall Maintenance Failure Probability calculated as the Sum of Products (See 6., above) divided by the Sum of Rates (see 5., above).

8. Standby time (ST) is measured directly during test or computed as total test time (TT) minus operating time (OT), Total Corrective Maintenance Time (TCM), Total Preventive Maintenance Time (TPM), and Total Administrative and Logistic Downtime (TALDT).

9. Operable Standby Time (ST_O) is calculated as one minus Overall Maintenance Failure Probability, multiplied by Standby Time.

10. Inoperable Standby Time (ST_i) is calculated as the Overall Maintenance Failure Probability multiplied by ST.

ST_O was calculated to be 2,709 hours and STi was calculated to be 968 hours, as shown in the table. These results will be used in calculating $A_{MANPRINT}$ for the MANPACK AUE.

The calculation of $A_{MANPRINT}$ for the MANPACK AUE is shown in Figure 3-6. As can be seen, MANPRINT Availability was calculated to be: 0.71. The acceptance of this level of $A_{MANPRINT}$ is dependent upon military criterion related to levels of $A_{MANPRINT}$ which are acceptable to the Army and can accomplish Army mission requirements which employ this system.

The GPS NAVSTAR Example...

$$A_M = \frac{OT + ST_O}{OT + ST_O + ST_I + TCM + TPM + TALDT}$$

$$= \frac{485.19 + 2709}{485.19 + 2709 + 968 + 162.32 + 0 + 154}$$

$$= .71$$

Figure 3-6

IV. EXAMPLES OF MANPRINT ANALYSES

The following examples of analyses on hypothetical MANPACK AUE data are intended to demonstrate how categorical and linear regression analyses can be used to help resolve MANPRINT issues and ultimately to improve system performance through improved soldier performance. One example analysis is provided for each of the six MANPRINT areas. Together, these analyses demonstrate the role that the methodology described in this handbook can have in evaluations of Army systems. They are not, however, comprehensive because they do not illustrate all possible types of analyses. Analysis is issue driven and the number of possible issues is innumerable. Different issues require different analyses. Therefore, these examples can only stimulate the user to conduct similar types of analyses.

Analysis Example: Manpower

Analysis of the Effects of a Potential Shortage of Soldiers in Maintenance MOS 31E and 31V.

Problem

What is the effect of excessive demands for maintenance MOS 31E and 31V upon the inventory of these types of soldiers due to the large number of systems to be fielded which demand these types of soldiers? How can analysis of MANPACK AUE test data identify means to reduce these effects? What recommendations can be made that would maintain (or enhance) system availability?

Background

In FY 1985, the percentage of accessions which were assigned to MOS drawn from the Electronics Repair (EL) aptitude area was 9% (of all Army accessions for that year). 31E and 31V soldiers (among others) are drawn from accessions using the EL scores of the ASVAB. 31E and 31V maintenance technicians are used to maintain equipment such as the MANPACK AUE. These soldiers are in short supply due to the excessive demand for these types of

MAINTENANCE PERFORMANCE DATA

Table 4-1

	Maintenance Performance Drivers*			ASVAB Composites		
Soldier	BIT Repair**	Sat. Loss** Repair time	Pm	EL	ST	GT
03	2.10	2.12	.21	115	118	126
06	1.98	2.16	.16	118	121	134
08	2.51	2.87	.45	1.6	86	112
21	2.48	2.71	.52	82	89	86
26	2.00	2.02	.08	123	126	108
34	2.19	2.62	.37	102	98	106
38	1.76	1.96	.00	136	128	111
40	2.18	2.62	.29	91	106	99
Mean	2.15	2.38	.26	109.1	109.0	110.3

*Maintenance Performance having greatest effect on operational availability
**Measured in Hours

personnel. The tester has an opportunity to assist the Army by suggesting alternatives which can reduce the demand for these soldiers (at least the demand for them in terms of the MANPACK AUE).

Analysis

To alleviate shortages created by high demands for these soldiers, the first step is to examine soldier performance and aptitude data for Army aptitude areas which are related to soldier performance of MANPACK AUE maintenance tasks. Since the EL aptitude area score is used as the basis for the selection of soldiers into the 31E and 31V MOS, and accounted for only 9% of Army accessions for 1985, it would prove beneficial to the Army to identify this and other aptitude areas from which equally competent soldiers can be drawn. Table 4-1 provides soldier performance data on three 'high driver' performance measures of MANPACK AUE maintenance for each maintenance technician. The table also presents the test participants' aptitude scores for: the Electronics Repair (EL), the Skilled Technical (ST), and the General Technical (GT) aptitude areas. The three high drivers of MANPACK maintenance include: 1) Built-in Test (BIT) failure repair time (measured in hours), 2) Satellite Loss Repair Time (also measured in hours), and 3) the probability that the MANPACK AUE will operate when the maintainer reports that the equipment has been completely repaired and will operate. These data are used in a linear regression (results shown in Table 4-2) of each of the three performance measures on each of the three aptitude area composite scores, to identify those aptitude areas which are predictive of performance on each of the three high driver performance measures. The results of this analysis are shown as correlations in the last column in Table 4-2. Both the EL and ST aptitude areas are related to each of the three performance measures.

These results can be used to suggest alternative supplies of maintenance manpower. For example, Table 4-3 shows that as the average aptitude area score for the MANPACK AUE maintainers increases (for both EL and ST), repair time required for successful maintenance decreases and the probability of failure to successfully maintain the MANPACK AUE also decreases. As a result, MANPRINT Availability (^{A}MANPRINT) increases. In practice the information may be

LINEAR REGRESSION ANALYSIS RESULTS

Table 4-2

Performance Measure	ASVAB Composite	Regression Equations	Correlation
Pm	EL	Pm=-.892 El+ 123.32	-.87
Pm	ST	Pm=-1.061 ST+141.65	-.97*
Pm	GT	Pm=-.671 GT+100.01	-.53
BIT Repair	EL	Time=-.0113 EL+3.38	-.79*
BIT Repair	ST	Time=-.0144 ST+3.72	-.95*
BIT Repair	GT	Tlme=-.00923 GT+3.17	-.53
Sat Loss Repair	EL	Time=-.0168 EL+4.21	-.82*
Sat Loss Repair	ST	Time=-.0212 ST+4.69	-.97*
Sat Loss Repair	GT	Time=-.0141 GT+3.94	-.56

*Significant Correlation

RELATIONSHIP OF ASVAB COMPOSITES EL AND ST TO OPERATIONAL AVAILABILITY

Table 4-3

Aptitude Area	Mean Score Of Maintainer Population	BIT Repair Time*	Sat Loss Repair Time*	P_m	A_o
EL	90	2.36	2.70	.43	.58
EL	100	2.25	2.53	.34	.65
EL	110	2.14	2.36	.25	.72
EL	120	2.02	2.19	.16	.80
ST	90	2.42	2.77	.46	.55
ST	100	2.28	2.57	.36	.63
ST	110	2.14	2.36	.25	.72
ST	120	1.99	2.15	.14	.81
Test		2.15	2.38	.26	.71

*Measured in Hours

used in two ways:

1) system availability can be predicted from the average aptitude area score for the MANPACK AUE maintainers, and

2) maintainers selected based on EL scores or on ST scores will be approximately equal in performance.

This finding can have substantial impacts on the demand for these expensive and rare maintenance technicians. The 1983 Army accessions for the ST aptitude area was 14%. This percentage, when combined with the 9% of overall 1983 Army accessions for the EL aptitude area, increases the MANPACK AUE maintainer selection pool to 23%. This can help alleviate the demand for these soldiers to support MANPACK in the field, and can potentially improve availability for similar systems which require these types of maintenance personnel.

Conclusions

ST aptitude area is an acceptable substitute for EL for selection of system maintainers.

The predicted effect of the substitution on system availability (AMANPRINT) is minimal.

Potential maintainer shortage in MOS such as 31E and 31V can be alleviated by drawing from MOS based on either EL or ST.

AMANPRINT is increased by using soldiers with higher EL or ST composite scores.

<u>Analysis Example: Personnel</u>

Analysis of the Effects of Soldier Aptitude Level on Operating the MANPACK AUE and on the Effectiveness of the NAVSTAR GPS.

Problem

Effectiveness of the NAVSTAR GPS is low due to the complexity of the MANPACK AUE. Can the effectiveness of the AUE be increased through the selection of higher mental aptitude soldiers as AUE operators?

Background

The design and operation for the

RELATIONSHIP OF SOLDIER MENTAL CATEGORY TO TASK PERFORMANCE AND SYSTEM EFFECTIVENESS

Table 4-4

	Mental Category				
TASK	**I/II**	**IIIA**	**IIIB**	**IV**	**TOTAL TEST**
P_i	.92	.72	.60	.36	.70
P_{pl}	1.00	.96	.92	.86	.95
P_{fs}	.92	.86	.88	.80	.87
P_r	1.00	1.00	1.00	1.00	1.00
P_S	.84	.59	.49	.25	.58
E	.67	.47	.39	.20	.46
n	2	5	2	1	10

MANPACK AUE is complex. This complexity increases cognitive and mental demands on the AUE operators. During testing, it was determined that system effectiveness was low due to longer performance time and and increase in errors while performing critical operator tasks (particularly for the AUE initialization task). The cause of lower soldier performance is shown through analysis of the soldier aptitude and performance relationships in the test data.

Analysis

The top half of Table 4-4 presents the soldier performance probabilities for each critical operator task in the mental categories of the test participants. With the exception of the battery replacement task (P_R), soldier performance declines on all critical tasks with mental aptitude. The AUE initialization task is particularly noteworthy for the range of soldier performance from the highest to the lowest mental category. Table 4-4 also presents the overall soldier performance probabilities and MANPRINT effectiveness levels as a function of the test participants' mental category. Overall soldier performance and system effectiveness decline as aptitude drops (from mental category I to IV). The bottom line in the Table presents the number of test participants in each mental category.

A further refinement can be achieved through analysis of the percentage of an expected users which fall into mental category I/II and those that fall into IIIA. Table 4-5 shows a 'what if' analysis indicating how the levels of soldier performance and system effectiveness can be expected to increase as mental category of operators increases. Table 4-5 can be interpreted to mean that the levels of soldier performance and system effectiveness can be expected to increase on average across the range of fielded MANPACKs, when mental category I and II soldiers increase over the percentage of mental category IIIA soldiers who are expected to operate the AUE. This table can be used as a rule of thumb to measure the system effectiveness levels obtained as a function of the ratio of high to medium aptitude soldiers.

Conclusions

Using higher mental aptitude soldiers to

WHAT IF: USE ONLY CAT I/II/IIIA SOLDIERS

Table 4-5

Proportion of User Population							
I/II	III A	P_i	P_{pl}	P_{fs}	P_r	Ps	E
30%	70%	.78	.97	.88	1.00	.66	.53
40%	60%	.80	.98	.88	1.00	.69	.55
50%	50%	.82	.98	.89	1.00	.72	.58
60%	40%	.84	.98	.90	1.00	.74	.59
70%	30%	.86	.99	.90	1.00	.77	.62
Test Values		.70	.95	.87	1.00	.58	.46

operate the MANPACK AUE can Increase the system effectiveness of the equipment.

A rule of thumb states that system effectiveness can be expected to increase as the ratio of high mental aptitude soldiers (MC I and II) to medium aptitude soldiers (MC IIIA) increases. This rule of thumb can be used to play 'what if' with the available population of high and medium mental aptitude soldiers.

The availability and cost of high mental category operators suggests that high soldier performance may require a redesign of the system, particularly the initialization task, to achieve needed effectiveness.

Analysis Example: Training

Analysis of the Effects of Time to Train to Proficiency on Operating the MANPACK AUE and on the Effectiveness of the AUE

Problem

Is established training time adequate to *achieve required proficiency in operating* the MANPACK AUE for the population of soldiers who are expected to operate the system?

Background

Test participants receive training for *system operation until they pass a test* demonstrating proficiency in performing tasks in AUE operations. Different participants receive different amounts of training, but all participants demonstrate approximately the same skill level after training.

Analysis

Table 4-6 shows the basic performance data on each of the critical tasks. It also shows overall soldier performance parameter (Ps) for each soldier which is obtained by multiplying all success probabilities on each critical task for each soldier. Also shown is *each participant's skilled technical* (ST) aptitude area score and the training time.

For purposes of analysis, the first interest is in whether there is any relationship between training time (TT) and soldier performance as measured by Ps. Table 4-7 shows a lack of correlation (= -.03) *between these two measures.* This supports the idea that the training provided brings the test participants to approximately the same skill level.

Table 4-6 Soldier Performance, Aptitude Scores and Training Data

Soldier	P_i	x P_{pl}	x P_{fs}	x P_r	= P_s	ST	Training Time (Hours)
02	.42	.90	.92	1.00	.35	86	48
04	.55	.96	.94	1.00	.50	98	42
07	1.00	1.00	1.00	1.00	1.00	132	32
10	.60	.86	.72	1.00	.37	126	40
11	.96	1.00	.82	1.00	.79	90	52
12	.91	.96	1.00	1.00	.87	116	[illegible]
13	.72	1.00	.78	1.00	.56	124	36
14	.84	.92	.76	1.00	.59	112	42
32	.51	1.00	.94	1.00	.48	118	36
42	.49	.90	.82	1.00	.36	104	44
mean	.70	95	.87	1.00	.58	110.6	41.2

The relationship between training time (TT) and aptitude (as measured by ST) is investigated. Table 4-7 shows the correlation between these variables to be -.91 indicating that lower aptitude soldiers require more training to reach a given skill level. A linear regression of TT on ST gives the equation shown in Table 4-7 which can be used to predict the training time required for a soldier if the soldier's ST score is known.

Table 4-8 shows how varying the ST scores of soldiers can affect the predicted training time required. These predictions can be made for individual soldiers, or for populations of soldiers with the indicated average ST scores. In general, a rule of thumb can be established which states that each increase of five points in ST score will reduce the training time required to achieve proficiency in operating the equipment by 1.3 hours.

Conclusions

40 hours of training will be sufficient to achieve the level of soldier performance demonstrated during the test <u>only</u> if the system operators have obtained an ST score of approximately 115 or higher.

If the average ST score of the system operators is 100, an average of approximately 45 hours of training will be needed to achieve the level of soldier performance of the test participants.

If soldier performance is to be improved over performance during the test through training (as opposed to other means of improvement, such as higher aptitude operators or improved human factors engineering), additional training time will be needed.

<u>Analysis Example: Human Factors Engineering</u>

Evaluation and analysis of Contractor X MANPACK/Vehicular Army User Equipment (AUE) for the Global Positioning System (GPS) on the Basis of Soldier Accuracy (Probability of success) in initializing the AUE.

Problem

The tester/independent evaluator has conducted an evaluation which has identified that soldier performance in initializing the MANPACK AUE is a major contributor to reduced NAVSTAR GPS system effectiveness. The tester has

RESULTS OF ANALYSIS: SOLDIER PERFORMANCE, TRAINING TIME, AND APTITUDE SCORES

Table 4-7

Correlations:

Training Time (TT) with Soldier Performance (Ps) = -.03

Skilled Technical (ST) Aptitude with Soldier Performance (Ps) =.52

Skilled Technical (ST) Aptitude with Training Time (TT) = -.91*

***significant**

Regression (Predict Training Time from Skilled Technical Aptitude):

$$TT = .34\ ST + 78.8$$

conducted human factors engineering analyses on two contractor prototypes which have identified design fixes for the system to improve the effectiveness of the AUE. These fixes were implemented by Contractor X in improving the design of the AUE for conducting the AUE initialization task. The upgraded AUE was tested again at a later date to measure the improvement in soldier performance with respect to AUE initialization and the associated increase in NAVSTAR GPS system effectiveness.

Background

The evaluation of system effectiveness revealed soldier performance as a major contributor to the effectiveness of the MANPACK AUE. Overall system effectiveness had been reduced due primarily to soldier performance. Decomposition of the soldier performance data can identify the specific causes of reduced effectiveness. The decomposition logic is shown below.

$$P_s = (P_i)(P_{pl})(P_{fs})(P_r)$$

Analysis

Using hypothetical data, soldier performance can be measured in operating the MANPACK AUE.

$$Ps = (\underline{.70})(.95)(.87)(1.0) = .58$$

When the soldier performance parameter (Ps) is decomposed into the probability of successful performance of critical operator tasks, it becomes evident that the initialization task is the 'high driver' in soldier performance which reduces the overall effectiveness of the MANPACK AUE. To help identify possible design improvements, performance on the initialization task for Contractor X can be compared with that for an alternative design by Contractor Y. Hypothetical data which represent the probability of successful AUE initialization by individual test participants for both Contractor X and Contractor Y AUE prototypes are shown in Table 4-9. These data are used to develop the overall initialization task performance probability (Pi) for the MANPACK AUE. As can be seen in the table, the overall probability of successful AUE initialization is higher for Contractor Y's prototype AUE than for Contractor X's. The explanation for the difference must lie in the design of the equipment since the same test subjects used each contractor's equipment. An assessment of the qualitative human factors data could be used to reveal features

RULE OF THUMB FOR ESTABLISHING INDIVIDUAL SOLDIER TRAINING TIME TO OBTAIN PROFICIENCY ON AUE OPERATIONS

Table 4-8

TO MAINTAIN THE SYSTEM EFFECTIVENESS ACHIEVED DURING TESTING	
If: The Average ST Score for System Operators is:	Then: The Predicted Average Training Time Required is:
90	48.2
95	46.5
100	44.8
105	43.1
115	39.7
120	38.0
125	36.3

between the two prototype AUEs which have an impact on operator use and error rates.

The analysis required to explain these results incorporates the use of additional quantitative and qualitative analyses. The quantitative analysis involved relating soldier performance and aptitude test scores (as shown in the example on Personnel). The qualitative analysis involves the use of human factors data collected through observations, surveys, and questionnaires used by human factors specialists during field tests. This analysis attempts to identify the human factors data related to equipment design (hardware and software) which either facilitate the use of the AUE by soldiers or make the AUE difficult for soldiers to operate and increase the soldier error rates (measured in terms of excessive time and errors) in operating the AUE.

The material contained in Tables 4-10 and 4-11 represents an extract from the human factors findings for Contractor X's and Y's AUE prototypes that were collected during prior testing that are related to set initialization.[1] These findings can be used to compare and contrast Contractor X's and Contractor Y's AUE prototypes. This qualitative data can be used to determine equipment design characteristics which have an impact on soldier performance as a means to determine recommended human factors engineering improvements.

Based upon these human factors findings which contribute to reduced soldier performance on initialization of the prototype AUE, Contractor X conducted the required engineering improvements to software and hardware in order to reduce soldier error in AUE initialization. The improved AUE was submitted to the tester for further field evaluations to measure the improvements

[1] Reference: U. S. Army Operational Test and Evaluation Agency. NAVSTAR GPS ARMY USER EQUIPMENT FIELD TRIALS REPORT. TR-OT-483. August 1985.

COMPARATIVE ANALYSIS OF CONTRACTOR X WITH CONTRACTOR Y MANPACK ARMY USER EQUIPMENT (AUE) FOR THE NAVSTAR GLOBAL POSITIONING SYSTEM (GPS) ON THE BASIS OF SOLDIER ACCURACY (PROBABILITY OF SUCCESS) IN INITIALIZING THE AUE.

Table 4-9

Player No.	Contractor X	Contactor Y
	P_i1	P_i
02	0.57	0.71
04	0.79	0.89
07	0.57	0.73
10	0.64	-NA-2
11	0.81	-NA-
12	0.65	0.77
13	0.78	0.89
14	0.61	-NA-
18	0.62	0.79
26	0.79	0.92
32	0.85	0.96
33	0.82	0.92
42	0.59	0.75
X	0.70	0.83

1. P_i refers to the probability of successful initialization of the AUE.

2. NA - Not applicable, means that this soldier did not operate the specific AUE.

obtained in soldier performance in initializing the AUE. The evaluation revealed that the engineering improvements identified through the analysis of the human factors engineering findings improved soldier performance on initialization. The revised soldier performance probability for initialization (Pi) was .92. The original value was .70. This resulted in a higher overall soldier performance probability (Ps) of .76. This increased the effectiveness (^{E}MANPRINT) of Contractor X's AUE to .60. The human factors engineering upgrades resulted in a 22% increase in soldier performance in the initialization task (Pi), which translated into an 18% increase in overall soldier performance (Ps) in operating the MANPACK AUE, and an 14% increase in overall system effectiveness (^{E}MANPRINT) for Contractor X's MANPACK AUE prototype.

Conclusions

Improvements in the human factors engineering of Contractor X's prototype MANPACK AUE resulted in:

- 22% improvement in soldier performance of the initialization task (Pi = .92),
- 18% improvement in overall soldier performance in operating the AUE (Ps = .76), and
- 14% increase in overall system effectiveness of the NAVSTAR GPS.

Analysis Example: System Safety

Analysis of the Effect of a Safety-Related Hardware Deficiency on Soldier Performance and System Effectiveness in Operating the MANPACK AUE

Problem

On numerous occasions during training and operation of the MANPACK AUE during testing, operators jammed fingers on sharp

Table 4-10.
SUMMARY OF HUMAN FACTORS ENGINEERING FINDINGS RELATED TO CONTRACTOR X MANPACK AUE INITIALIZATION

- Data entry errors:
  - no provision in software for 'zeroing' system failure memory following AUE start-up*
  - accidental shut-off of AUE easily occurs due to knob design*
  - Excessive keystrokes for AUE initialization (380 keystrokes)
  - Alpha characters require excessive keystrokes:*require two sequential keystrokes per alpha character (a control key and alpha key)
  - inadequate keyboard labelling
  - excessive use of multiple function keys*
  - inconsistent procedures in use of special function keys*
  - highlighting of keys on keyboard unrelated to frequency of key use*
  - zero ('0') key and alpha character 'O' key occupy same key on keyboard*
  - unit of measure in data processed by AUE is unfamiliar to AUE operators (i.e., nautical miles as opposed to kilometers)*
  - few and inadequate prompts to AUE operators
  - vocabulary used by existing prompts require excessively high readability grade level for AUE operator*

- Entered data verification errors:
  - no provision in software for 'zeroing' system failure memory following AUE start-up*
  - lack of error messages provided to AUE operator*
  - AUE software alters displayed entries which causes operator confusion*
  - AUE requires operator to view display at 90o (degrees) to be visible and readable*
  - AUE display flickers causing operator eye fatigue*
  - lower case alpha characters are distorted and hard to read (they are also unnecessary)*
  - inadequate prompts and displays provided to AUE operator
  - vocabulary used by existing prompts require excessively high readability grade level for AUE operator*
  - lack of feedback of AUE self-test feedback provided to operator during self-test*

- Excessive data entry time:
  - accidental shut-off of AUE easily occurs due to knob design*
  - lack of error messages provided to AUE operator*
  - Alpha characters require excessive keystrokes:* require two sequential keystrokes per alpha character (a control key and alpha key)
  - inadequate keyboard labelling
  - excessive use of multiple function keys*
  - inconsistent procedures in use of special function keys*
  - AUE requires operator to view display at a 90o (degree) and six to be visible and readable*
  - AUE display flickers causing operator eye fatigue*
  - lower case alpha characters are distorted, hard to read, and unnecessary)*
  - unit of measure in data processed by AUE is unfamiliar to AUE operators (i.e., nautical miles as opposed to kilometers)*
  - data clearing time consuming due to lack of key repeat function for data clearing key*

---

* Denotes human factors findings which were identified in Contractor X's AUE prototype, but were not identified in Contractor Y's.

Table 4-11.
SUMMARY OF HUMAN FACTORS ENGINEERING FINDINGS RELATED TO CONTRACTOR Y MANPACK AUE INITIALIZATION

Summary of Initialization Task Deficiencies Related to MANPRINT

- Data entry error causes:
  - top-level prompting for set initialization sequence is non-existent
  - unlabelled multiple function keys
  - excessive keystrokes for data entry
  - inconsistent use of CLR and ENT
  - inadequate keyboard tactile feel

- Excessive data entry time:
  - unlabelled multiple function keys
  - excessive keystrokes for data entry
  - inconsistent use of CLR and ENT
  - inadequate keyboard tactile feel

Entered data verification errors:

  - top-level prompting for set initialization sequence is non-existent
  - leading and following zeros in display

raised ridges surrounding keys on the CDU. This led to immediate discomfort for the soldier, and may have had some impact on performance of the two critical soldier tasks requiring data entry: initialization and position location. In field settings (especially under combat conditions), this problem can be expected to increase operator errors in initializing the AUE and determining waypoints during missions.

Analysis

Table 4-12 shows the performance data on the two critical tasks possibly affected by the safety problem. The first two columns show the overall performance for each participant during the test. The third and fourth columns show the performance of the four soldiers who jammed fingers only for the trials during which fingers were jammed. The last two columns show soldier performance only on trials during which no jammed fingers were experienced. Comparing performance in the first two columns with performance in the last two columns indicates a minimum amount of performance can be improved by removing the safety hazard. The bottom two lines in Table 4-12 show overall soldier performance (Ps) and system effectiveness ($E_{MANPRINT}$). In each case, removing the safety problem led to an increase of .01 -- a small, but nonetheless possibly useful increase, particularly in comparison with the cost of removing the hazard by rounding of the sharp raised edges.

Conclusion

The safety hazard has a small effect on system effectiveness. Elimination of the safety hazard can be expected to increase system effectiveness by about two percent.

Analysis Example: Health Hazards

Analysis of the Effect of a Potential Health Hazard Associated with Lithium Batteries on Soldier Performance and System Effectiveness in Operating the MANPACK AUE

Problem

Does the lithium battery that has been designated as the primary power source for the MANPACK AUE present a hazard to the health of system operators? If so, how does this hazard affect system effectiveness?

Background

The lithium battery, when punctured,

Table 4-12 . System Safety Example

Soldier	Performance as Tested		Performance with Jammed Fingers		Performance without Jammed Fingers	
	P_i	P_{pl}	P_i	P_{pl}	P_i	P_{pl}
02*	.42	.90	.22	.72	.44	.92
04	.55	.96			.55	.96
07	1.00	1.00			1.00	1.00
10*	.60	.86	.48	.82	.61	.89
11	.96	1.00			.96	1.00
12*	.91	.96	.70	.78	.93	.98
13	.72	1.00			.72	1.00
14	.84	.92			.84	.92
32	.51	1.00			.51	1.00
42*	.49	.90	.30	.82	.51	.91
mean	.70	95			.71	.96
P_s	.58				.59	
E_m	.46				.47	

*Indicated participants snagged fingernails during ten percent of their trials.

will release an acid that can burn the operator. This hazard is particularly dangerous if the acid comes into contact with a soldier's eyes. In addition to the potential immediate direct effect of this hazard on the soldier's health, it can also potentially reduce the effectiveness of the system by disabling the operator. Based on standard procedures for operating the system for the purpose of analyzing the effect of this health hazard on overall system effectiveness, we assume that when the usual operator is disabled, operation of the system is undertaken by another soldier who has not had complete training on the system but has had short familiarization training. When operated by this backup the system may have reduced effectiveness because of reduced soldier performance.

Analysis

The basic analysis is shown in Table 4-13. This quantitative analysis shows the effect of the health hazard -- battery puncture -- on system effectiveness, (^{A}MANPRINT). The first line in the table shows the basic soldier performance and system effectiveness data for operators from the OT. These data can be compared with the performance data for backup operators with only familiarization data shown on the second line. These data were obtained from four typical backup operators with typical familiarization training. The difference in soldier performance and therefore in ^{E}MANPRINT is dramatic. Line three, however, shows predicted overall soldier performance and system effectiveness based on an estimate that the health hazard would occur with probability .01 or one percent of the times the system is operated. This estimate was obtained through risk analysis conducted as part of the health hazard analysis.

Conclusion

The health hazard posed by the potential to puncture the lithium battery has minimal effect on system effectiveness. The need to reduce this health hazard should be decided on the basis of the direct effects on soldier health rather than by its effect on system performance.

Table 4-13 . Analysis Results

Task Performance

Condition	P_i x	P_{pl} x	P_{fs} x	P_r =	P_s x	P_E =	E_M
No hazard encountered* (original operators)	.70	.95	.87	1.00	.58	.80	.46
Original operator disabled** Replaced by backup	.40	.85	.84	.90	.26	.80	.21
Overall performance***	.697	.949	.870	.999	.57	.80	.456

*Data from original test participants with usual trainig.

**Data from four participants typical of backup operators with only familiarization training.

***Based on health hazard analysis indicating a .01 probability of hazard. These data represent a weighted average of the no hazard data (weight = .99) and the disabled operator data (weight = .01).

APPENDIX

SOLDIER PERFORMANCE WORKSHEETS AND INSTRUCTIONS

A. OPERATOR PERFORMANCE WORKSHEET
B. CORRECTIVE MAINTENANCE PERFORMANCE WORKSHEET
C. PREVENTIVE MAINTENANCE PERFORMANCE WORKSHEET
D. PERSONNEL DATA FORM
E. SUMMARY OF OPERATOR PERFORMANCE DATA FOR INDIVIDUAL SOLDIER
F. SUMMARY OF OPERATOR PERFORMANCE FOR SYSTEM EFFECTIVENESS
G. MANPRINT SYSTEM EFFECTIVENESS WORKSHEET
H. SUMMARY OF CORRECTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER
I. SUMMARY OF CORRECTIVE MAINTENANCE FOR SYSTEM AVAILABILITY
J. SUMMARY OF PREVENTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER
K. SUMMARY OF PREVENTIVE MAINTENANCE FOR SYSTEM AVAILABILITY
L. TOTAL CORRECTIVE MAINTENANCE (TCM) TIME WORKSHEET
M. TOTAL PREVENTIVE MAINTENANCE (TPM) TIME WORKSHEET
N. STANDBY TIME (ST) WORKSHEET

APPENDIX A

OPERATOR PERFORMANCE WORKSHEET

I. ADMINISTRATION

1. Test Participant: ______________________________
2. Social Security Number: ________________________
3. Task: ____

   ____
4. Test Conditions: ____________________________________

   ____

   ____
5. Data Source: ______________________________
6. Data Collector/Observer: ______________________________
7. Date: ______________ 8. Time: ______________

II. PERFORMANCE

1. TASK SUCCESSFULLY COMPLETED: YES ____ NO ____
2. TASK COMPLETION TIME: ______________________

III. PERFORMANCE DESCRIPTION

INSTRUCTIONS FOR COMPLETING THE OPERATOR PERFORMANCE WORKSHEET

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player. It should also provide a number identifier which is unique to each test participant and is unrelated to the test participant so as to not permit identification. The number identifier sequence should be determined by the MANPRINT test manager.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will permit the MANPRINT analyst to obtain aptitude and training information on each test participant from appropriate Army personnel data bases. Its use is for this purpose and no other.

3. TASK. This item should contain a complete statement of the task being observed or recorded on this worksheet. It should contain a description of the task and associated performance standard. This information should be pre-filled on the form during test set-up by the MANPRINT analyst.

4. TEST CONDITIONS. This item should describe the circumstances of the soldier performance to be observed and recorded on this form. This item should be pre-filled during test set-up by the MANPRINT analyst. The test conditions are defined during the planning phase of the test and are shown on each form as required. Example test conditions include: day vs. night operations, MOPP 4 clothing used vs. not, electronic warfare present vs. not).

5. DATA SOURCE. This item should describe the test or data collection vehicle. These probably include: (a) operational test, (b) technical (or developmental) test, (c) force development test and experimentation, and (d) contractor (or prototype) test. This item should be pre-filled during test set-up.

6. DATA COLLECTOR/OBSERVER. This item should contain the name and number identifier of the data collector/observer who observed and recorded soldier performance on this worksheet.

7. DATE. This item should contain the date of data observation and recording.

8. TIME. This item should contain the time of day that observation and recording took place.

B. SECTION II. PERFORMANCE

1. TASK SUCCESSFULLY COMPLETED. The data collector should score the soldier performance of a single trial of a task as either a "YES" (i.e., the task was successfully performed) or "NO" (i.e., the task was incorrectly performed). The appropriate block should be checked.

2. TASK COMPLETION TIME. The time observed by the data collector/observer from the start of a task to its completion by a soldier will be recorded on this line.

C. SECTION III. PERFORMANCE DESCRIPTION

This section should be used by a data collector/observer for recording comments and observations made during the observation of task performance by a soldier. This should include information on errors and difficulties observed or expressed by the data collector/observer or the test participant. The source of the comments should be noted as either the data collector/observer or the test participant. Of special note should be the

involvement of hardware, software, operator manuals, and any other support equipment and materials used in the performance of a task. Events which might have led to an error or excessive task completion time should also be noted if observed or expressed by either the data collector/observer or test participant. It is important to describe task performance both successful and unsuccessful.

CORRECTIVE MAINTENANCE PERFORMANCE WORKSHEET

I. ADMINISTRATION

1. Test Participant: ______________________

2. Social Security Number: ______________________

3. a. Equipment Item: ______________________

   b. Failure Mode: ______________________

   c. Conditions: ______________________

   ____

   ____

4. Data Source: ______________________

5. Data Collector/Observer: ______________________

6. Date: ______________ 7. Time: ______________

II. PERFORMANCE

1. PREPARATION TIME:* ______________
2. FAULT LOCATION TIME: ______________
3. ITEM OBTAINMENT TIME: ______________
4. FAULT CORRECTION TIME: ______________
5. ADJUSTMENT/CALIBRATION TIME: ______________
6. CHECKOUT TIME: ______________
7. CLEANUP TIME: ______________

Does the equipment operate after maintenance? YES ____ NO ____

III. PERFORMANCE DESCRIPTION

*Use NA when task is not performed.

INSTRUCTIONS FOR COMPLETING THE CORRECTIVE MAINTENANCE PERFORMANCE WORKSHEET

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player. It should also provide a number identifier which is unique to each test participant and is unrelated to the test participant so as to not permit identification. The number identifier sequence should be determined by the MANPRINT test manager.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will permit the MANPRINT analyst to obtain aptitude and training information on each test participant from appropriate Army personnel data bases. Its use is for this purpose and no other.

3. a. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance will be observed. This item should be pre-filled during test set-up.

b. FAILURE MODE. This item should contain a one sentence description of the failure mode for which data will be collected during observation of maintenance. This item should be pre-filled during test set-up except in the case of unanticipated maintenance requirements which occur during the test conduct.

c. CONDITIONS. This item should describe the circumstances of the soldier performance to be observed and recorded on this form. This item should be pre-filled during test set-up by the MANPRINT analyst. The test conditions are defined during the planning phase of the test and are shown on each form as required. Example test conditions include: day vs. night operations, MOPP 4 clothing used vs. not.

4. DATA SOURCE. This item should describe the test or data collection vehicle. These probably include: (a) operational test, (b) technical (or developmental) test, (c) force development test and experimentation, and (d) contractor (or prototype) test. This item should be pre-filled during test set-up.

5. DATA COLLECTOR/OBSERVER. This item should contain the name and number identifier of the data collector/observer who observed and recorded soldier performance on this worksheet.

6. DATE. This item should contain the date of data observation and recording.

7. TIME. This item should contain the time of day that observation and recording took place.

B. SECTION II. PERFORMANCE

1. CORRECTIVE MAINTENANCE TASKS. This item should contain the response times for completion of the seven maintenance tasks being observed or recorded on this worksheet. The time observed by the data collector/observer from the start of a task to its completion by a soldier will be recorded on this line. NA (not applicable) should be pre-filled on the form during test set-up for all tasks for which no data will be collected. If any maintenance tasks are repeated as part of the same maintenance activity (for example, if checkout shows that the equipment still does not work properly so fault location and subsequent tasks have to be performed again) times for these tasks should be recorded as separate entries on the same lines as the original times. If separate entries are made, the final entry on each line (each maintenance task) should be the sum of entries for that task.

2. DOES THE EQUIPMENT OPERATE AFTER MAINTENANCE? The data collector should designate successful operation of an item of equipment after maintenance as either a "YES" (i.e., the equipment was successfully operated) or "NO" (i.e., the equipment failed to operate). The appropriate block should be checked. This item should be completed only after all maintenance, including any repetitions of tasks has been completed so that in the opinion of the maintainer(s), the equipment should operate.

C. SECTION III. PERFORMANCE DESCRIPTION

This section should be used by a data collector/observer for recording comments and observations made during the observation of task performance by a soldier. This should include information on errors and difficulties observed or expressed by the data collector/observer or the test participant. The source of the comments should be noted as either the data collector/observer or the test participant. Of special note should be the involvement of hardware, software, maintenance manuals, and any other support equipment and materials used in the performance of a task. Events which might have led to an error or excessive task completion time should also be noted if observed or expressed by either the data collector/observer or test participant. It is important to describe task performance both successful and unsuccessful.

APPENDIX C

PREVENTIVE MAINTENANCE PERFORMANCE WORKSHEET

I. ADMINISTRATION

1. Test Participant: ______________________________

2. Social Security Number: ______________________________

3. a. Equipment: ______________________________

   b. Type of Maintenance: ______________________________

   c. Conditions: ______________________________

   ____

   ____

4. Data Source: ______________________________

5. Data Collector/Observer: ______________________________

6. Date: ____________________ 7. Time: ____________________

II. PERFORMANCE

1. MAINTENANCE COMPLETION TIME: ______________________________

2. Does the equipment operate after maintenance? YES ____ NO ____

III. PERFORMANCE DESCRIPTION

INSTRUCTIONS FOR COMPLETING THE PREVENTIVE MAINTENANCE PERFORMANCE WORKSHEET

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player. It should also provide a number identifier which is unique to each test participant and is unrelated to the test participant so as to not permit identification. The number identifier sequence should be determined by the MANPRINT test manager.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will permit the MANPRINT analyst to obtain aptitude and training information on each test participant from appropriate Army personnel data bases. Its use is for this purpose and no other.

3. a. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance will be observed. This item should be pre-filled during test set-up.

b. TYPE OF MAINTENANCE. This item should contain a one sentence functional description of the type of maintenance observed. This item should be pre-filled during test set-up.

c. CONDITIONS. This item should describe the circumstances of the soldier performance to be observed and recorded on this form. This item should be pre-filled during test set-up by the MANPRINT analyst. The test conditions are defined during the planning phase of the test and are shown on each form as required. Example test conditions include: day vs. night operations, MOPP 4 clothing used vs. not.

4. DATA SOURCE. This item should describe the test or data collection vehicle. These probably include: (a) operational test, (b) technical (or developmental) test, (c) force development test and experimentation, and (d) contractor (or prototype) test. This item should be pre-filled during test set-up.

5. DATA COLLECTOR/OBSERVER. This item should contain the name and number identifier of the data collector/observer who observed and recorded soldier performance on this worksheet.

6. DATE. This item should contain the date of data observation and recording.

7. TIME. This item should contain the time of day that observation and recording took place.

B. SECTION II. PERFORMANCE

1. MAINTENANCE COMPLETION TIME. This item should contain the response times for completion of the maintenance task being observed or recorded on this worksheet. The time observed by the data collector/observer from the start of a task to its completion by a soldier will be recorded on this line. NA (not applicable) should be pre-filled on the form during test set-up for all tasks for which no data will be collected.

2. DOES THE EQUIPMENT OPERATE AFTER MAINTENANCE? The data collector should designate successful operation of an item of equipment after maintenance as either a "YES" (i.e., the equipment was successfully operated) or "NO" (i.e., the equipment failed to operate). The appropriate block should be checked.

C. SECTION III. PERFORMANCE DESCRIPTION

This section should be used by a data collector/observer for recording comments and observations made during the observation of task performance by a soldier. This should include information on errors and difficulties observed or expressed by the data collector/observer or the test participant. The source of the comments should be noted as either the data collector/observer or the test participant. Of special note should be the involvement of hardware, software, maintenance manuals, and any other support equipment and materials used in the performance of a task. Events which might have led to an error or excessive task completion time should also be noted if observed or expressed by either the data collector/observer or test participant. It is important to describe task performance both successful and unsuccessful.

PERSONNEL DATA FORM

A. To be completed by test participant.

1. NAME:________________ 2. DATE: ________________

3. MOS: ________________ 4. ASI: ________________

5. SSN: ________________ 6. SKILL LEVEL: ________________

7. GRADE: ________________ 8. POSITION: ________________

9. EXPERIENCE (MONTHS): __________ 10. BIRTHDATE: ________________

11. HEIGHT: ________________ 12. WEIGHT: ________________

13. LENGTH OF SERVICE: __________ years, __________months.

14. CIVILIAN EDUCATION: (a) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 (circle no. of years.)

    (b.) Major area (if applicable): ______________________________

B. To be completed for each test participant by test personnel.

15. PHYSICAL PROFILE: P U L H E S

    _ _ _ _ _ _

16. APTITUDE SCORES: ASVAB COMPOSITE: ________________

    AFQT: ________________

    MENTAL CATEGORY: ________________

17. LATEST SQT SCORE: ________________________

18. END-OF-TRAINING TEST SCORE: ____________________

19. LIST OF MILITARY SCHOOLS AND COURSES COMPLETED:

____

____

____

INSTRUCTIONS FOR COMPLETING THE PERSONNEL DATA FORM

SECTION A. INFORMATION PROVIDED BY TEST PARTICIPANT.

1. NAME. The full name of the test participant should be entered in this item.

2. DATE. The current date should be entered on this item.

3. MOS. The current Military Occupational Specialty of the test participant should be entered in this item.

4. ASI. Any Additional Skill Identifier currently held by the test participant should be entered on this line.

5. SSN. The test participants Social Security Number should be entered on this line.

6. SKILL LEVEL. The current skill level of the test participant within their current MOS should be entered on this line.

7. GRADE. The current grade of the test participant should be entered on this line.

8. POSITION. The duty position currently held in the test participants non-test related job should be entered on this line.

9. EXPERIENCE (MONTHS). The amount of experience in the current MOS should be entered on this line.

10. BIRTHDATE. The test participants birthdate should be entered on this line.

11. HEIGHT. The height of the test participant should be entered on this line.

12. WEIGHT. The weight of the test participant should be entered on this line.

13. LENGTH OF SERVICE. The length of military service of the test participant should be entered on this line by total years and months.

14. CIVILIAN EDUCATION. The number of years of civilian education obtained by the test participant should be circled. In addition, major area of specialty should be entered, if applicable.

SECTION B. COMPLETION BY TEST PERSONNEL.

15. PHYSICAL PROFILE. This information will be obtained from the Army personnel data bases. It includes:

P - xxxxxxxxx
U - xxxxxxxxx
L - xxxxxxxxx
H - xxxxxxxxx
E - xxxxxxxxx
S - xxxxxxxxx

16. APTITUDE SCORES. This information includes:

a. ARMED SERVICES VOCATIONAL APTITUDE BATTERY (ASVAB) COMPOSITE SCORE.

b. ARMED FORCES QUALIFICATION TEST (AFQT) SCORES.

c. MENTAL CATEGORY: This is a number between 1 (one) and 5 (five), based upon the following mental category ranges:

TEST SCORE CATEGORY (TSC)	SCORE RANGE
1. TSC I.	xxx - xxx
2. TSC II.	xxx - xxx
3. TSC IIIA.	xxx - xxx
4. TSC IIIB.	xxx - xxx
5. TSC IV.	xxx - xxx

17. LATEST SKILL QUALIFICATION TEST (SQT) SCORE. This item should contain the most current SQT score available for the test participant - in the current MOS.

18. END-OF-TRAINING TEST SCORE. This item should contain the score obtained by the test participant on the test conducted following training for the current test program.

19. LIST OF MILITARY SCHOOLS AND COURSES COMPLETED. This item should contain a list of all military schools and courses completed during the career of the test participant.

SUMMARY OF OPERATOR PERFORMANCE DATA FOR INDIVIDUAL SOLDIER

I. ADMINISTRATION

1. Test Participant: ______________________________
2. Social Security Number: ______________________________
3. Test Condition: ______________________________

II. PERFORMANCE

1. TASK: ______________________________
   a. Number of successes: ____________
   b. Number of trials: ____________
   c. % Success: ____________
   d. Average Task Completion TIme: ____________
2. TASK: ______________________________
   a. Number of successes: ____________
   b. Number of trials: ____________
   c. % Success: ____________
   d. Average Task Completion TIme: ____________
3. TASK: ______________________________
   a. Number of successes: ____________
   b. Number of trials: ____________
   c. % Success: ____________
   d. Average Task Completion TIme: ____________
4. TASK: ______________________________
   a. Number of successes: ____________
   b. Number of trials: ____________
   c. % Success: ____________
   d. Average Task Completion Time: ____________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF OPERATOR PERFORMANCE DATA FOR INDIVIDUAL SOLDIER

This form will be used (in as many copies are required) to summarize the task performances for a single individual soldier. It includes summaries for the individual soldier on each operator task that are obtained from all of the Operator Performance Worksheets for the individual soldier.

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player and should also provide a number identifier. This information will be obtained from the collection of Operator Performance Worksheets for an individual soldier.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will be obtained from the collection of Operator Performance Worksheets for an individual soldier.

3. TEST CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Operator Performance Worksheets for an individual soldier.

B. SECTION II. PERFORMANCE.

1. TASK. All tasks that were performed by a single individual soldier will be shown on this form. (Multiple summary worksheets may be required to summarize the performance of all tasks by a single individual soldier.) This information will be entered from the Operator Performance Worksheets.

a. NUMBER OF SUCCESSES. The analyst will enter the count (frequency) of the number of times the task was performed successfully by a single individual soldier. This information will be determined from the Operator Performance Worksheets, "yes" on item II.1., for a single individual soldier.

b. NUMBER OF TRIALS. The analyst will enter the number of times the task was performed (either successfully or unsuccessfully) by the individual soldier for the indicated operator task. This information will be determined from the Operator Performance Worksheets for the individual soldier (total number of "yes" and "no" on item II.1).

c. % (PERCENT) SUCCESS: The analyst will divide the number of task performance successes (a. above) by the number of task performance trials (b. above) to determine the percentage of successes of task performance for a single individual soldier. The analyst will enter the resulting percentage on this line.

d. AVERAGE TASK COMPLETION TIME: The analyst will sum the amount of task completion time from item II.2 of the Operator Performance Worksheet across all trials of a task and divide by the number of task performance trials (b. above) to determine the Average Task Completion Time for a single individual soldier in performing the same task. This average will be entered onto this line.

APPENDIX F

SUMMARY OF OPERATOR PERFORMANCE FOR SYSTEM EFFECTIVENESS

I. ADMINISTRATION

1. TASK: ____________________

2. TEST CONDITIONS: ____________________

II. PERFORMANCE

1. AVERAGE % SUCCESSES: ____________________

2. AVERAGE TASK COMPLETION TIME: ____________________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF OPERATOR PERFORMANCE FOR SYSTEM EFFECTIVENESS

This form will be used to summarize performance of a task by all soldiers. A separate form will be required for each critical operator task. Completion of this form will use the Summary of Operator Performance for Individual Soldier forms.

A. SECTION I. ADMINISTRATION

1. TASK. The task that was performed will be shown on this form. (Separate summary worksheets will be required for each task.) This information will be determined from the Summary of Operator Performance for Individual Soldier forms.

2. TEST CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Summary of Operator Performance for an Individual Soldier forms.

B. SECTION II. PERFORMANCE.

1. AVERAGE % (PERCENT) SUCCESSES: The analyst will sum the task % success from item c. of the Summary of Operator Performance Data for an Individual Soldier form for all soldiers performing the task and divide by the number of soldiers to determine the average percentage of successes of task performance. The analyst will enter the resulting average percentage on this line.

2. AVERAGE TASK COMPLETION TIME: The analyst will sum the average task completion times from item d. of the Summary of Operator Performance Data for an Individual Soldier form and divide by the number of soldiers to determine the Average Task Completion Time in performing the task. This average will be entered onto this line.

MANPRINT SYSTEM EFFECTIVENESS WORKSHEET

(1)	(2)	(3)	(4)	(5)
CRITICAL SOLDIER TASK	TEST CONDITIONS (TC)			
	TC 1	TC 2	TC 3	TC 4
(6) $P_{SOLDIER} =$				
(7) $P_{MATERIEL} =$				
(8) $P_{MANPRINT} =$				

NSTRUCTIONS FOR COMPLETION OF THE FORM:

MANPRINT SYSTEM EFFECTIVENESS WORKSHEET

This form will be used to calculate MANPRINT System Effectiveness.

1. CRITICAL SOLDIER TASKS. This item list all critical soldier tasks for which soldier performance data was to be collected. (See item 1.)

2. TEST CONDITIONS (TC). This item should list all test conditions for which different measures of effectiveness will be calculated. Enter a probability of success estimate for each critical operator task from the Summary of Operator Performance for System Effectiveness worksheet in the column for each test condition. (See items 2 - 5.)

3. $P_{soldier}$. Multiply these probabilities of success together to obtain an overall soldier performance parameter (Psoldier) for each test condition. (See item 6.)

4. $P_{Materiel}$. Enter an overall materiel performance success probability for each test condition. (See item 7.)

5. $E_{MANPRINT}$. Enter the product of multiplying Psoldier (item 6) times Pmateriel (item 7) for each test condition. This provides the overall measure of effectiveness, MANPRINT Effectiveness, for each test condition. (See item 8.)

SUMMARY OF CORRECTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER

I. ADMINISTRATION

1. Test Participant: ______________________________

2. Social Security Number: ______________________________

3. a. Equipment Item: ______________________________

   b. Failure Mode: ______________________________

   c. Conditions: ______________________________

   ____

   ____

II. PERFORMANCE

A.

	Number of Trials	Average Time
1. PREPARATION	________	________
2. FAULT LOCATION	________	________
3. ITEM OBTAINMENT	________	________
4. FAULT CORRECTION	________	________
5. ADJUSTMENT/CALIBRATION	________	________
6. CHECKOUT	________	________
7. CLEANUP	________	________

B.

1. Number of Maintenance Performances: ______________________________

2. Number of Times Equipment Operated After Maintenance: ________________

3. % Successes: ____________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF CORRECTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER

This form will be used (in as many copies are required) to summarize the task performances for a single individual soldier.

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player and should also provide a number identifier. This information will be obtained from the collection of Corrective Maintenance Performance Worksheets representing an individual soldier.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will be obtained from the collection of Corrective Maintenance Performance Worksheets representing an individual soldier.

3. a. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance was observed. This information will be obtained from the collection of Corrective Maintenance Performance Worksheets representing an individual soldier.

b. FAILURE MODE. This item should contain the one sentence description of the failure mode for which data was collected during observation of maintenance. This information will be obtained from the collection of Corrective Maintenance Performance Worksheets representing an individual soldier.

c. CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Corrective Maintenance Performance Worksheets representing an individual soldier.

B. SECTION II. PERFORMANCE.

A.

1. CORRECTIVE MAINTENANCE TASKS. This item should contain the number of trials of a maintenance task by the individual soldier and the average times for completion of each of the seven maintenance tasks observed or recorded on the worksheet. All tasks that were performed by a single individual soldier will be shown on this form. This information will be entered from the Corrective Maintenance Performance Worksheets. If a Corrective Maintenance Performance Worksheet shows multiple times for a task (that is, the task was repeated during the maintenance activity) for the purpose of the summary, it should be counted as one trial and the total time should be used to calculate the average task completion time.

B.

1. NUMBER OF MAINTENANCE PERFORMANCES. The analyst will enter the count (frequency) of the number of corrective maintenance performances on a single failure mode for an item of equipment by a single individual soldier. This information will be determined from the Corrective Maintenance Performance Worksheets for a single individual soldier.

2. NUMBER OF TIMES EQUIPMENT OPERATED AFTER MAINTENANCE. The analyst will enter the number of times an item of equipment operated after corrective maintenance. This

information will be determined from the Corrective Maintenance Performance Worksheets for a single individual soldier.

3. % (PERCENT) SUCCESS: The analyst will divide the number of times the equipment operated after corrective maintenance (2. above) by the number of maintenance performances (1. above) to determine the percentage of successes for corrective maintenance for a single individual soldier. The analyst will enter the resulting percentage on this line.

APPENDIX I

SUMMARY OF CORRECTIVE MAINTENANCE FOR SYSTEM AVAILABILITY

I. ADMINISTRATION

1. Equipment Item: ______________________________
2. Failure Mode: ______________________________
____
3. Conditions: ______________________________
____
____
____

II. PERFORMANCE

A.

	Average Time
1. PREPARATION	________
2. FAULT LOCATION	________
3. ITEM OBTAINMENT	________
4. FAULT CORRECTION	________
5. ADJUSTMENT/CALIBRATION	________
6. CHECKOUT	________
7. CLEANUP	________

B. AVERAGE % SUCCESS OF EQUIPMENT OPERATION AFTER MAINTENANCE ____________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF CORRECTIVE MAINTENANCE FOR SYSTEM AVAILABILITY

This form will be used to summarize all performances of corrective maintenance. A separate form will be required to summarize corrective maintenance for each failure mode for each critical item of equipment.

A. SECTION I. ADMINISTRATION

1. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance was observed. This information will be obtained from the collection of Summary of Corrective Maintenance Performance for Individual Soldier forms.

2. FAILURE MODE. This item should contain the one sentence description of the failure mode for which data was collected during observation of corrective maintenance. This information will be obtained from the collection of Summary of Corrective Maintenance Performance for Individual Soldier forms.

3. CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Summary of Corrective Maintenance Performance for Individual Soldier form.

B. SECTION II. PERFORMANCE.

A. AVERAGE CORRECTIVE MAINTENANCE TASK TIME. This item should contain the average time in performance of each of the seven maintenance tasks observed or recorded on the Summary of Corrective Maintenance for Individual Soldier form item II.A. It is calculated by summing the "average time" for the task across all individual soldiers performing the identified maintenance activity and dividing by the number of soldiers.

B. AVERAGE % (PERCENT) SUCCESS OF EQUIPMENT OPERATION AFTER MAINTENANCE.

This value is the average of "% successes," item II.B.3. from the Summary of Corrective Maintenance for Individual Soldier forms for all soldiers performing corrective maintenance for the identified equipment and failure mode. It is calculated by summing the "% successes" across all individual soldiers and dividing by the number of soldiers. The analyst will enter the resulting percentage on this line.

SUMMARY OF PREVENTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER

I. ADMINISTRATION:

1. Test Participant: ______________________________

2. Social Security Number: ________________________

3. a. Equipment Item: ____

   b. Failure Mode: ____

   c. Conditions: ____

   ____

   ____

II. PERFORMANCE

1. Number of Trials: ____________________
2. Average Maintenance Completion Time: ____________________
3. Number of Times Equipment Operates After Maintenance: ____________________
4. % Successes: ____________________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF PREVENTIVE MAINTENANCE FOR INDIVIDUAL SOLDIER

This form will be used to summarize the preventive maintenance performances for a single individual soldier.

A. SECTION I. ADMINISTRATION

1. TEST PARTICIPANT. This item should contain the full name of the test participant/player and should also provide a number identifier. This information will be obtained from the collection of Preventive Maintenance Performance Worksheets representing a single individual soldier.

2. SOCIAL SECURITY NUMBER. This item should contain the correct social security number for each test participant. This information will be obtained from the collection of Preventive Maintenance Performance Worksheets representing an individual soldier.

3. a. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance was observed. This information will be obtained from the collection of Preventive Maintenance Performance Worksheets representing an individual soldier.

b. TYPE OF MAINTENANCE. This item should contain the one sentence description of the type of maintenance for which data was collected during observation of maintenance. This information will be obtained from the collection of Preventive Maintenance Performance Worksheets representing an individual soldier.

c. CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Preventive Maintenance Performance Worksheets representing an individual soldier.

B. SECTION II. PERFORMANCE.

1. NUMBER OF TRIALS. The analyst will enter the count (frequency) of the number of preventive maintenance trials for a single type of maintenance. This information will be determined from the Preventive Maintenance Performance Worksheets representing a single individual soldier.

2. AVERAGE MAINTENANCE COMPLETION TIME. The analyst will sum the preventive maintenance completion times for the individual soldier from the Preventive Maintenance Performance Worksheets and divide by the number of trials (1. above) to determine the Average Maintenance Completion Time in performing the task. This average will be entered onto this line.

3. NUMBER OF TIMES EQUIPMENT OPERATES AFTER MAINTENANCE. The analyst will enter the number of times an item of equipment operated after preventive maintenance. This information will be determined by summing the number of times the equipment operates after maintenance for an individual soldier from the Preventive Maintenance Performance Worksheets.

4. % (PERCENT) SUCCESSES: The analyst will divide the number of times the equipment operated after preventive maintenance (3. above) by the number of trials (1. above) to determine the percentage of successes for preventive maintenance for a single individual soldier. The analyst will enter the resulting percentage on this line.

APPENDIX K

SUMMARY OF PREVENTIVE MAINTENANCE FOR SYSTEM AVAILABILTY

I. ADMINISTRATION

1. Equipment Item: ______________________________

2. Type of Maintenance: ______________________________

   ____

3. Conditions: ______________________________

   ____

   ____

   ____

II. PERFORMANCE

1. AVERAGE PREVENTIVE MAINTENANCE COMPLETION TIME: ____________

2. AVERAGE % SUCCESS OF EQUIPMENT
   OPERATION AFTER MAINTENANCE: ____________

INSTRUCTIONS FOR THE COMPLETION OF THE FORM:

SUMMARY OF PREVENTIVE MAINTENANCE FOR SYSTEM AVAILABILITY

This form will be used to summarize all performances of preventive maintenance. A separate form will be required to summarize each type of preventive maintenance.

A. SECTION I. ADMINISTRATION

1. EQUIPMENT ITEM. This item should contain a common name and number identifier for the critical item of equipment for which soldier performance was observed. This information will be obtained from the collection of Summary of Preventive Maintenance Performance for Individual Soldier forms.

2. TYPE OF MAINTENANCE. This item should contain the one sentence description of the type of maintenance for which data was collected during observation of preventive maintenance. This information will be obtained from the collection of Summary of Preventive Maintenance Performance for Individual Soldier forms.

3. CONDITIONS. This item should describe the test conditions which were in effect during collection of the summarized data. This information will be obtained from the collection of Summary of Preventive Maintenance Performance for Individual Soldier forms.

B. SECTION II. PERFORMANCE.

A. AVERAGE PREVENTIVE MAINTENANCE COMPLETION TIME. This item should contain the average completion time for preventive maintenance, observed or recorded as item II.2 on the Summary of Preventive Maintenance for Individual Soldier form. It will be determined by summing average maintenance completion times across all soldiers and dividing by the number of soldiers. The result should be entered on this line.

B. AVERAGE % (PERCENT) SUCCESS OF EQUIPMENT OPERATION AFTER MAINTENANCE. This item is calculated by summing the % of successes, item II.4. of the Summary of Preventive Maintenance for Individual Soldier form, across all soldiers performing this type of preventive maintenance, and dividing by the number of soldiers performing this type of preventive maintenance. The analyst will enter the resulting percentage on this line.

TOTAL CORRECTIVE MAINTENANCE (TCM) TIME WORKSHEET

CRITICAL EQUIPMENT (I)	FAILURE MODE (J)	MINUTES							HOURS			
		PT	FLT	IOT	FCT	ACT	CT	CUT	CMij	Fij	(Fij)(CMij)	TCMi

TCM=

PT=Preparation Time
FLT=Fault Location Time
IOT=Item Obtainment Time
FCT=Fault Correction Time
ACT=Adjustment Calibration Time

CT=Checkout Time
CUT=Cleanup Time

INSTRUCTIONS FOR COMPLETION OF THE FORM:

TOTAL CORRECTIVE MAINTENANCE (TCM) TIME WORKSHEET

This form will be used to calculate total corrective maintenance (TCM) time for use in calculating MANPRINT availability.

1. CRITICAL EQUIPMENT (i). This item lists the critical items of equipment which require corrective maintenance.

2. FAILURE MODE (j). This item lists the failure modes which may occur for each critical item of equipment.

3. For each piece of critical equipment and each failure mode enter the average times for each maintenance task from the Summary of Corrective Maintenance for System Availability worksheets. These data should be entered for each of the seven maintenance tasks.

4. CM_{ij}. Enter the sum of the row entries in columns PT through CUT for the seven maintenance tasks.

5. F_{ij}. Obtain the failure rate, f_{ij}, for each critical item of equipment and each failure mode, and enter it. (These failure rates should be available from RAM data.) It is important that each rate have comparable units of time, e.g., per day, per month, etc. If available failure rates are measured in units other than time, e.g., per hour of operation, per round fired, per mile driven, per mission performed, etc., these rates must be transformed into rates with time units by determining the usage rate, for example, the hours of operation per unit time. The parameter f is then determined by multiplying the failure rate in non-time units by the usage rate:

f (measured in failures/unit time) = failures/non-time unit x (number of non-time units/unit time).

6. $F_{ij}.CM_{ij}$. Enter the product of fij and CM_{ij}, the two preceding columns.

7. TCM_i. Sum the $f_{ij}.CM_{ij}$ entries over all failure modes and enter this sum in the TCMi column (one entry for each piece of critical equipment).

8. TOTAL CORRECTIVE MAINTENANCE (TCM) TIME. This item can be computed by summing TCM_i over all pieces of critical equipment. The result can be entered in the bottom right side of the worksheet.

TOTAL PREVENTIVE MAINTENANCE (TPM) TIME WORKSHEET

TYPE OF MAINTENANCE (k)	PMT	RATE (r)	(PMT)(r)

PMT=Preventive Maintenance Time

TPM=

INSTRUCTIONS FOR COMPLETION OF THE FORM:

TOTAL PREVENTIVE MAINTENANCE (TPM) TIME WORKSHEET

This form will be used to calculate total preventive maintenance (TPM) time for use in calculating MANPRINT availability.

1. TYPE OF MAINTENANCE (k). This item lists each of the various types of preventive maintenance that may be required.

2. MEAN PREVENTIVE MAINTENANCE TIME (PMT). This item lists the mean time to perform the required maintenance measured during testing or otherwise available.

3. RATE (r). This item lists the rate at which each type of preventive maintenance occurs, i.e., how often it is performed.

4. MEAN PREVENTIVE MAINTENANCE TIME MULTIPLIED BY RATE (PMT)(r). This item lists the product of (PMT) multiplied by (r), to provide a measure of total maintenance time for the identified type of maintenance in a given time period -- calculated as column 2 times column 3.

5. TOTAL PREVENTIVE MAINTENANCE TIME (TPM). This item is calculated as the sum of column 4 (PMT)(r).

STANDBY TIME (ST) WORKSHEET

TYPE OF MAINTENANCE				
CORRECTIVE				
CRITICAL EQUIPMENT	FAILURE MODE	Pm	RATE	PRODUCT (Pm x Rate)
PREVENTIVE				

Pm =
OVERALL ST =
ST_i =
STo =

INSTRUCTIONS FOR COMPLETION OF THE FORM:

STANDBY TIME (ST) WORKSHEET

This form will be used to calculate standby time for use in calculating MANPRINT availability.

TYPE OF MAINTENANCE. This form should contain data on both corrective and preventive maintenance.

A. CORRECTIVE MAINTENANCE.

1. CRITICAL EQUIPMENT. This item should list the critical items of equipment for corrective maintenance (and in addition, the type of maintenance) for preventive maintenance.

2. FAILURE MODE. This item should list the failure modes for each critical item of equipment. (Ignore this column for preventive maintenance.)

B. PREVENTIVE MAINTENANCE.

This form should list the types of preventive maintenance below the corrective maintenance information.

3. PROBABILITY OF MAINTENANCE FAILURE (P_M) This item should list the probability that the system is not restored to an operable status and that this failure is not recognized by maintenance personnel for the given type of maintenance -- measured during test.

4. RATE. This item should list the the number of times the given type of maintenance is performed in a given time period. <u>All rates must be for the same period of time.</u>

5. PRODUCT OF THE PROBABILITY OF MAINTENANCE FAILURE TIMES THE RATE (PM X Rates). This item is computed by multiplying column 3 by column 4.

6. P_M. This item is the overall Maintenance Failure Probability (PM) calculated as the Sum of Products (Sum of column 5, above) divided by the Sum of Rates (Sum of column 4).

7. OVERALL STANDBY TIME (ST). This item is measured directly during test or computed as total test time (TT) minus operating time (OT), Total Corrective Maintenance Time (TCM), Total Preventive Maintenance Time (TPM), and Total Administrative and Logistic Downtime (TALDT).

8 INOPERABLE STANDBY TIME (ST_i). This item is calculated as P_M (See 5., above) multiplied by Overall ST.

9. *OPERABLE STANDBY TIME* (ST_O). This item is calculated as one minus P_M multiplied by Overall ST.